DISTRIBUTION AND UTILIZATION OF UNDER-GROUND WATER RESOURCES IN UTTAR PRADESH

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CERTIFICATE

This is to certify that Miss Syeda Shadab Fatima has completed her dissertation on 'Distribution and Utilization of Under-Ground Water Resources in Uttar Uttar', for the award of the degree of M.Phil under my supervision.

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S. Shadab Fatima
(Syeda Shadab Fatima)

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INTRODUCTION

Water is mankind's most crucial resource. As a result of the massive increase in population during the last few decades and an ever-accelerating rate of economic development; pressure on water resources has correspondingly increased. In many parts of the world water resource situation has already become critical. In the coming decades, therefore, availability of water resources is going to become the greatest constraint on economic development. Conservation and rational utilisation of our water resources should therefore be given top priority in national planning strategies.

The present study is a modest attempt at studying the distribution and utilisation of groundwater resources of Uttar Pradesh, one of the most populus and underdeveloped state of India.

The basic objective of the groundwater surveys of Uttar Pradesh is to evaluate the occurrence, availability, and quality of groundwater. For this purpose it has become very important to assess usable groundwater resources on district level. In order to keep a watch on the groundwater situation in diverse hydrogeological conditions, relative response of groundwater levels to dynamic and interactive agencies, changes in chemical qualities of groundwater and its effects on soils, ever-increasing development activities and their after effects, 553 national hydrograph stations have been established. Periodic monitoring at these stations is being carried out by Central Groundwater Board in order to evaluate the qualitative and quantitative changes in the groundwater system. Data which have been collected from these stations by Central Groundwater Board have proved helpful in understanding the behaviour of water table as also hydrogeochemical characteristics of groundwater consequent upon various natural processes and human activities in force. These form the basis for planning and the management of groundwater resources of the state.

Valuable informations regarding administrative divisions, land utilisation, irrigation, rainfall, water level data, chemical analysis of groundwater have been collected from various sources e.g. Statistical Diary of Uttar Pradesh Government and the Office of Central Groundwater Board, Northern Region, Lucknow. After collection of datas from various sources, they have been processed and maps have been prepared. This technique has served as a tool in the interpretation of the problem under review. The methodology adopted in the present study reflects a resume of the methods used by the author with a view to finding out the occurrence and behaviour of groundwater in the study area. A district has been taken as the unit area of the study. This attempt may be considered as a modest beginning and may serve as an appropriate basis on which further advanced work in the field of groundwater studies can be done.

This dissertation deals with the status of regional hydrogeological studies, hydrogeological setting, groundwater exploration, district-wise occurrence and behaviour of groundwater, quality of groundwater and assessment of district-wise ultimate and usable groundwater resources. This dissertation also deals with the present utilisation of groundwater and scope of further groundwater development.

The present work is divided into five chapters. Chapter one discusses the conceptual parameters of resource. The second chapter deals with water resource, while the third one has been devoted exclusively to groundwater resource. The fourth chapter contains discussion about the geographical introduction of Uttar Pradesh and the last chapter studies the occurrence and behaviour of groundwater in Uttar Pradesh.

The present study is the preliminary part of larger doctoral dissertation that will be taken up after the successful completion of this work.

CHAPTER I

RESOURCE

Resources can be defined as things which participate in the fulfilment of man's needs and goals. Therefore, nothing is a resource in itself. In fact its resourcefulness is latent in the capability of satisfying human needs.

According to Zimmerman, "neither the environment, as such nor parts or features of the environment per se are resources; they become resources only if, when, and in so far as they are considered to be, capable of serving man's needs".[1]

In a revised edition Zimmerman stressed that natural resources are dynamic, becoming available to man through a combination of increased knowledge and expanding technology, as well as changing individual and societal objective.

In his words, "resources are not, they become; they are not static but expand and contract in response to human wants and human actions".[2]

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1 Zimmerman, E.W., World Resources and Industries, London, 1933, p.3.

2 ibid., 1951, p.15.

J.L. Guha opines that usefulness to man is the most prominent characteristic of resource. According to him, "A thing becomes resource by its function in relation to man"[1].

Hooder and Rodger Lee have defined resources in a different style, "Resources are inputs to the process of production and they generate a flow of productive services, known as factors of production, when used in combination by firms"[2].

In this definition Hooder and Rodger Lee described resources as an input of productivity. In their expert opinion resources beget a flow of productivity.

According to Zimmerman the resource concept is subjective and relative. "The word 'resource' is an expression of appraisal and hence a purely subjective concept. The resource appraisal proceeds from human wants and human power to use, both wants and powers are subjective attribute of the appraisel".

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1 Guha, J.L. and Chattoraj, P.R., A New Approach to Economic Geography: A Study of Resources, Calcutta, 1964, p.3.

2 Hooder, B.W. and Rodger Lee, Economic Geography, New York, 1974, p.84.

The relativity of resources is twofold, for the resource aspect of environment vary not only according to human wants, but also according to the abilities of man to make use of environment. That environment viewed as resources is a function of human wants and abilities. Hence the concept of resource is also functional.[1]

Resources may be defined in various ways according to the importance of subjective, relative and functional aspects such as, "1)"Resources are the environment appraised to its usefulness to man. 2) Resources are the environment viewed in its relation to human wants and abilities. 3) Resources are the environment functioning to satisfy human needs.[2]

The concept of resource is highly controversial. The followers of the static school believe that resources in the world are static and fixed and weather they are developed or under-developed, they are all resources.

According to the exponents of modern dynamic school resources are functional and operational. A thing may become resource only when it is capable of satisfying human needs. Things which are not utilised by man are neutral

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1 Zimmerman, E.W., 1933, op. cit., p.4.

2 ibid.

stuff and not resources. Human knowledge aggravates the capabilities of resources. In fact resource expansion is an integral part of human wants and capabilities.

Resource is a dynamic concept. It is not fixed. It expands and contracts in response to human wants, abilities and his attitude. The concept of resource has therefore no meaning until pressed to promote human interest. It is to be taken as a neutral thing if it does not become a factor in human welfare, because all things become useful when human skill utilises them for the welfare of mankind.

CLASSIFICATION OF RESOURCES

With the progress and development of human culture, utilisation rate of resources has also increased. Generally resources are classified according to their capabilities of satisfying human needs. A classification of resources can be made on two basis, first according to its capacity of renewal and secondly, on the basis of availability and distribution.

1. Classification on the Basis of its Capacity of Renewal

According to this point of view resources can be divided into two groups:

A. Exhaustible Resources

1. Sustainable, Increasable and Improvable Resources: These resources can be maintained for a long period with the help of advanced technology. Quality of this type of resources can be increased and improved. Agriculture, forest and soil belong to this category.

2. Non-increasable, Non-improvable and Depletable Resources: These resources are fund resources and will be exhausted with continuous use. Its quality cannot be improved with the help of human skill and technology. These resources can be classified into three groups:

i) Fund resources, which are non-renewable and will be exhausted for ever such as, coal, gass and petroleum.

ii) Some re-usable resources such as sulpher, tin, boron belong to this group but their recovery ratio is very limited.

iii) Some resources are characterised by high ratio of recovery for reuse such as gold, silver, iron and copper.

B. Inexhaustible Resources

(Non-increasable and Non-depletable flow Resources). These resources are inexhaustible and non-depletable. They can be divided into two groups.

1) Immutable Resources: Flow resources which cannot be affected or destroyed by man in any form are immutable resources. Macro climate, solar energy etc. belong to this category.

2) Misusable Resources: Flow resources which may destroyed or changed (in a limited ratio) by man such as landscape, micro climate etc. belong to this category of resources.

<u>Classification on the Basis of Availability and Distribution</u>

Natural resources are not evenly distributed on the earth. Their distribution varies greatly in terms of quantity, variety and frequency of occurrence. On the basis of frequency of occurrence Zimmerman classifies the natural resources as follows:

1) "Ubiquities (occurring everywhere, e.g., oxygen in the air);

2) Commonalities (occurring in many places, e.g., tillable soil);

3) Rarities (occurring in few places, e.g., tin);

4) Uniquities (occurring in one place, e.g., commercial cryolite)".[1]

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1 Zimmerman, E.W., 1951, op. cit., pp.81-82.

Important enough is the frequency of occurrence. Coal and iron for example may occur so frequently that it may be considered quite usual, but usable combination of the two may be rare. A distinction has, however, to be made between physical presence and availability.

A distinction is also necessary between absolute and relative rarity. Availability of tin, for example is quite limited whereas aluminium is common. Even then aluminium is relatively rare because only rich deposits of this metal are exploited keeping in view the cost of recovery and market price.

Ratio also has variation of its own. The rarity of aluminium is not so important for the kitchen utensil industry as it is in the case ofaeroplane industry. On account of its extreem lightness and vital use.

Flow and Fund Resources: With the frequency of occurrence the question of exhaustibility or permanency of resources is interlinked. An exhaustible resource gives rise to more serious problems than a self-renewable one. Coal for example is a fund resource whereas water power is a typical flow resource. The former is exhausted through use but the letter is usually self-renewable.

All fund resources are not exhaustible, because some of them are revolving. Iron, for instance may be used in the form of steel and cost iron but after many years of use it can be scrapped and remelted and rendered available for further use. Lead and several other metals are also revolving fund resources.

'Silted' or 'Choked' Flow Resources: An analogy can be drawn between a flow resource and a stream. As a stream can be silted up by sand, mud and deteritus, so can flow resources become silted or choked. Forests can yield a stream of products endlessly, if managed properly. It may get 'silted' or choked up by over-cutting or other such misuse. Since the abuse of flow resources can pose a danger to civilisation it must not be allowed to become silted or choked up. In the coming years we have to rely on flow resources more than the fund resources because the latter is more liable to be exhausted.

Animate and Inanimate, Organic and Inorganic Matter: The classification of matter into dead and living is not identified with the division into organic and inorganic matter but it is related to each other. For instance, carbon is the element of life, and without it there is no life. It is also true that in certain cases carbon is found into dead objects, as fossilized ones. It may, however, be said that is preserved both in living organism and their derivatives and fuels.

Primary and Secondary Aspects of Nature

There are two aspects of nature; primary and secondary. By primary we also mean the original aspect of nature, whereas the secondary aspect means altered, modified and harnessed ones to serve the interest of mankind. This modification and alteration of a natural object form the part of human culture and be termed natural cultural resources.

Direct and Indirect Factors: The natural resources are further divided in terms of their relation to the process of production as well as consumption. Moreover, the production factors help us distinguish between the resources that function directly, such as soil, coal, wood, animals with regard to the production process and which have indirect effect such as topography, ecology, environment, phenomenology etc.

The Process of Resource Emergence: The process of resource emergence depends upon certain circumstances which are pre-requisite for resource emergence.

First, the element must occur. It can be naturally occurring, man made or even believed to exist without actually existing.

Second, Man must recognize and appraise the element, and the appraisal must be positive. He must decide that use of element is beneficial toward achieving his objective.

Third, We must possess the ability to acquire the element (technology). If aquisition cannot be affected the elements does not function directly as a resource.

Fourth, The element is actually acquired and used.[1]

The functioning of any element of the environment as a resource is preceded by almost a common process. The element must either occur or exist. It can occur in a natural way, can be made to occur or even believed to exist, though not existing in point of fact. The element, however must be recognized or appraised in a positive manner. As a pre-requisite man must have the ability to acquire the element failing which the element is bound not to act

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1 Griffin, F. Paul., et al., Culture, Resource and Economic Activity: An Introduction to Economic Geography, London, 1976, p.18.

directly as a resource. It must need be emphasized that the element is, as matter of fact, acquired and put to use.

Effectiveness of Resources: The ideal economic efficiency of resource in a society can form the basis of determining its effectiveness. Significantly enough, the needs of the society using the resources should be kept in view while determining their effectiveness.

Trend of Resource Development: Resource development emanates from human wants and knowledge and the expansion of both takes place simultaneously. As our wants and knowledge go on increasing we create more and more resources. We go on transforming neutral stuffs and often resistence into resources but we must, nevertheless, keep in mind that while man produces enormous resources, he also destroys them because with the progress of knowledge and culture many neutral stuffs are changed into resources and many old resources fall into disuse and resume their earlier forms of neutral stuffs.

In the words of Demitri B. Shimkin, "Resource development is a process in which the natural endowments of an area and of its population are captured by appropriate management, productive skills, and technology for the end uses of household consumption, public service, defence, capital accumulation (including that of knowledge), and exportation".[1]

Resource Creating Factors

Man, nature and culture are responsible for resource appraisal. They can be helpful in attaining human welfare to a considerable extent. In fact the function of man nature and culture determine the resourcefulness of an object. All these factors play an important role in the determination of resources. Therefore man nature and culture may be regarded as resource creating factors. All these things can function as means for attaining the goal of human welfare.

Nature: Various substances of nature are resource and simultaneously they are responsible for the creation of resource. Nature contains all the things whether they survive on the earth and are influenced by human beings, or the things which are not affected by human beings. Nature in its primitive and unaffected state may be regarded as a resource base. Resourcefulness of natural substances is

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1 Clawson, M. (ed.), Natural Resources and International Development, Baltimore, 1964, p.157.

latent in man's skill and his sincere efforts. Undoubtedly nature provides the physical base to man, on which he can display his skill. On the basis of this function nature is a resource creating factor.

Man: Man himself is a resource and even more importantly he is a resource - creating factor and creates resources for his own welfare.

A man who exists on animal level is always surrounded by neutral stuffs but since he lacks technology he cannot be a creator of resources. Contrary to this, a man who is culturally advanced, and possesses advanced technology is the creator of resources. With his expanding knowledge and with the help of advanced technology he creates more and more resources. Man is the most important resource - creating factor. Nature provides him a physical base, upon which he can display his skill. With the help of culture he exploits the nature.

Culture: Many items of culture are resources. At the sometime they are also the resource - creating factors. Culture is the consequence of an interaction of man and nature. In fact culture plays an important role in the determination of resources.

Resource Appraisal: Human wants and Social Objectives: Appraisal is the centre of gravity for the resource process. Human wants social objectives, current human contribution to want satisfaction; and environment are capable to regulate and develop the process of resource appraisal we can divide human wants into two groups:

1. Basic Wants
2. Cultural Wants

1) Basic Wants

Basic wants must be satisfied for the maintenance of individual as well as group life. These wants change according to age, sex, standard of living, habitat and also according to racial characteristics.

Basic wants can be further divided into positive and negative wants. Positive wants includes food, air and water which is necessary for building up bones and tissues.

The negative wants include such requirements of human being as protection from cold, disease and attack of wild animal. These include shelter and clothing etc. In the words of Zimmerman, "Basic wants are the starting point of the economic process and consequently of resource appraisal"![1]

2) Cultural Wants

Man cannot live by merely fulfilling his basic wants in a crude way. Human nature has also got a teste for the beautiful things, so he refines the way in which he fulfills his wants. In this way culture and refinement also become part of human life and mode of living. The satisfaction of want is also governed by social sanctions and establish social habits which crystallize into group standard of living. These become parts of basic human wants. If this is threatend in any way the individual and the society resists such threats to its establish culture.

Wants and Want Doctrines: The wants determine the standard of living in addition to this doctrines are formulated about wants. These doctrine can be divided into positive and negative doctrine. Negative doctrine discourages wants and push up the standard of living. At sometimes this tendency is also checked and an attitude of resignation develops which is prevalent in primitive society. Among

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1 Zimmerman, E.W., op. cit., 1951, p.21.

the sophisticated people it may take the form of discouragement of asceticism because the ascetic seeks the happiness in self denial and supperession of wants.

The opposite view point i.e., positive philosophy of want encouragement, rests on the belief that material progress leads to happiness and for the expansion and multiplication of wants is necessary.

The Nature of Wants and Economic Implications: The nature demands a minimum of satisfaction as well as a maximum. All elementary wants are subject to this law. It is called law of absolute limitation. Cultural wants are different they are neither subject to maximum or minimum set by nature. They are also non recurring as against the basic wants which are recurring such as appetite.

Individual Wants and Social Objectives: The appraisal of usefulness of environment to man from two different angles:

i) From the stand point of individual humand wants.

ii) Social point of view.

In an ideal society the attainment of social objective resulting fuller satisfaction of human wants for social aim and individual wants run parallel to each other.

Resource Appraisal: Technological and Societal Arts: Man can be easily differentiated from animal due to his properties of active adaptation. He is capable to change the environment according to his will. It is he, who alone can make cultural endowments expansible and changeable at will. Man successfully brings into existence the cultural environment, because nature adorned him with sharp brain-power, exceptional vocal organs, strong arms and hands with firm grip; simultaneously he is benefited by the cultural heritage of his ancestors. Culture is a cumulative process; this process obtains swiftness as it advances.

Arts and Capital Equipment; Technological and Institutional Arts: We can classify the cultural improvement into to group.

A) Tangible Changes of Natural Environment

It consists of all those changes which are physically existing and we can tocuh then. Tangible changes may be called artifacts or capital equipment.

B) Intangible Cultural Changes

It involves those changes which are not physically existing we even cannot touch them but we can realise them such as knowledge, technology, acquired skill etc.

"Arts generally function through equipments".[1] Man's changing needs and social objectives always make a positive influence on the resource appraisal, yet it ultimately depends on the condition of the arts.

Two categories of the arts may be distinguished:

A) Material or Technical Arts: This type of art is capable of harnessing matter and energy into human use. The arts which prove helpful in the development of material culture are material or technical arts.

B) Societal or Institutional Arts: These are capable to regulate and improve human relations. In fact the art which play a dominant role in supporting and promoting social culture are societal or institutional arts.

Technological and societal arts are complementary to each other.

Functional Classification of Arts: There are many types of arts and their purpose, and it is consequently difficult to classify them in any coherent way.

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1 Zimmerman, E.W., op. cit., 1951, p.31.

Zimmerman's functional classification of the arts is as follows:

Functional Classification of the Arts

I. Arts designed to enlarge capacity, raise human efficiency, and thus promote the economy of human energy.

A. Arts designed to improve health and to extend the duration of life, and thus to improve general efficiency.

1. Preventive and curative medicine and surgery.
2. Mental hygiene.
3. Contraception and other methods which permit rationalized control of population increase. Birth control affects generally favourably, the age composition of the population, and thus the ratio of productive to unproductive (or less productive) age group.

B. Arts designed to better the performence of the individual.

1. Those which directly raise the efficiency of human activity.

a) Education, training etc., which improve the intellectual capacity, character and spiritual qualities of man and bring about a better adaptation of the work to the work.

b) Ways and means which improve the functioning of human organs and refine the perception of the sense, such as eye glasses, hearing aids, skates, radio etc.

c) Arts of using tools and simple machines which extend the reach and in general raise the effectiveness of the human body, such as hammer, pulley etc.

d) Arts of using devices which permit the appropriation of "foreign" energy such as turbines, winnd mills, internal-combustion engines etc.

e) Arts of using modern complicated and automatic machines.

2. Those which indirectly raise the efficiency of human activity.

a) Methods of increasing the mobility of man (this is mainly accomplished with the aid of appropriated foreign energy, e.g., riding on horse back, riding in a train, driving an automobile, flying in an airplane, etc.; this is of great importance since it expands the sphere to which man can apply his activity).

b) Ways of improving the social relations between men or groups of men by eliminating wasteful conflict.

c) The general increase of human knowledge of facts and laws of nature.

II. Arts designed to render nature more amenable to human use.

A. Ways and means of enlarging the supply of usable matter and energy.

1. Arts making possible the fuller exploitation of available supplies (e.g., the application of air pressure to oil wells for the purpose of recovering supplies of petroleum which cannot be produced by ordinary methods).

2. Arts making possible the fuller utilisation of products obtained (e.g., the application of the cracking process to the production of gasoline).

3. Arts permitting the recovery of waste materials, the use of by-products and the reuse of "secondary" materials (e.g., the manufacture of celotex from cane pulp, bagasse; the manufacture of artificial leather, fabrikoid, from cotton seed; the manufacture of steel from scrap).

4. Arts transforming substances from a less useful to a more useful form (e.g.; the manufacture of rayon out of cotton linters).

B. Arts designed to change the form of matter or energy so as to render it usable (e.g., transfarming the gravitational energy of Niagra falls into electric energy, or transfarming poisonous plants into valuable food by cooking).

C. Arts which render matter and energy mobile or increase their mobility (these are generally the same as those which make for greater mobility of man)".[1]

This functional classification of the arts throws light on the diversity and multiplicity of the ways and means by which civilization is advanced.

CONSERVATION

Principle of resource conservation establishes balanced adjustment between natural resources and population. Optimum utilisation of resources and development in various field of life such as social economic and political field is possible due to this adjustment.

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1 Zimmerman, E.W., op. cit., 1951, pp.32-33.

It is far from the reality that non-use of resources is conservation. In fact optimum and rational use of resources is conservation. We can say that proper rate of utilization and exploitation is known as conservation.

Fude has said, "conservation is not to refrain from resources use. It is neither stinginess nor spendthrift, but mederation in consumption. It is prudent use of resources, elimination of waste".[1]

In fact elimination of waste, wise and optimum use of resource is conservation.

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1 Fude, I., Conservation of Resources, Indian Journal of Power and River Valley Development, Vol.XXXV, No.9, Calcutta, 1985, p.164.

CHAPTER II

WATER RESOURCE

Water is an inexhaustible natural resource which is most universally and constantly in demand. No one can imagine the existence of living organism in the absence of this precious resource. The atmosphere and the oceans contain large quantity of water which is more than enough to meet all needs. However, water of usable quantity is not inexhaustible.

Our entire civilization is based upon the availability of water. The earlier civilizations of the world were evolved in river basins, where the facility of water was available and modern industrial civilization is too based on water resource.

Water resource is unique in certain respects. It belongs to the category of commonality. Water unlike other resources is characterised by interdependency. The extraction of water from one point affects the availability of water at another place. This interdependency becomes more visible in the case of ground water.

THE WATER CYCLE

The supply of fresh water is dependent on the working of hydrological cycle, which regulates the circulation of all moisture between the various storage units within the earth-atmosphere system. "The atmosphere contains only 0.035 per cent of all fresh water. The water content of the atmosphere is equivalent to approximately 25 mm of precipitation distributed evenly over the globe and, with a mean precipitation rate approaching 1000 mm per anum. This indicates an average residence time of only 10 days for each water molecule".[1]

The process of evaporation and precipitation regulates the hydrological cycle and this cycle controls the terrestrial water balance. The source of most of the rain is the ocean. Air masses, which are situated over the ocean and seas pick up water through evaporation. When these air masses rush towards the continents much of this water which they containd falls out as precipitation.

When water falls on the earth in the form of rain, snow, sleet hail or surface condensation it becomes useful to human being, excess, running off the surface. Considerabl

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1 Smith, K., Principles of Applied Climatology, London, 1975, p.116.

amount of the water is consumed by the vegetation, and is partly absorbed by the earth. The balance is returned to the atmosphere by evaporation from vegetation, soil, streams rivers and lakes.

Water which has penetrated into the ground is known as ground water and may reappear as base flow into streams, ponds or lakes maintaining the level of these bodies of water during dry season.

Generally when the amount of rainfall is sufficient and the ground is porous, some water percolates through to add to underground storage, some will run-off to add to stream flow and eventually reach the ocean.

WATER BALANCE

Ocean is the basic reservoir of water. 77 per cent of all type of precipitation is received by the oceans while the quantity of evaporation from the ocean is 84 per cent. Evaporation from the ocean surfaces totals about 109,000 cu.m per year and from the continents totals about 15,000 cu.m. The total amount of evaporation is 124,000 cu.m. The total amount of precipitation is also 124,000 cu.m out of which 98,000 cu.m is received by the oceans and the remaining 26,000 cu.m is received by the land surfaces. The land surfaces receive 11,000 cu.m more water as precipitation than they lose by evaporation.[1] In fact precipitation is unevenly divided between oceans and land surfaces.

Smith has states, "The gross availability of water resources is primarily determined by precipitation, and the latitudinal distribution of the water balance components".[2]

Seasonal water balance governs gross water resources and local scale.

SOURCES OF WATER SUPPLY

For water supply we largely depend on rain when it reaches the ground, part of it flows into rivers, lakes, ponds, streams etc. and is known as surface water. Some portions of it reverts to the atmosphere due to evaporation and the remaining reaches the subsoil water lable. Water supply schemes employ the surface and the ground sources of water supply. These sources are as follows:

1. Surface sources

   i) River, streams and lakes

   ii) Reservoirs

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1 Strahler, A.H. and Strahler, A.N., Geography and Man's Environment, New York, 1977, p.94.

2 Smith, K., 1975, op. cit., p.117.

2. Ground Sources

   i) Springs

   ii) Shallow Wells

   iii) Artesion Wells

Surface Water

1) Rivers : River water is the largest source of water supply. It is highly polluted particularly when sewage is discharged into the river either after full or partial treatment. The most important characteristic of the river water is its property of self-purification. River water purifies itself in a few hour after sewage is discharged into it. Sunlight, sedimentation, dilution and aerabic bacteria take part in the purification of river water. It is very likely that river water may be softer than underground water.

ii) Stream: It is a long narrow body of flowing water occupying a trench like depression and moving a lower levels under the force of gravity. Streams depend on comparatively smaller catchment areas than rivers and hence the run-off is smaller. Therefore streams provide smaller quantities of water.

iii) Lake: Lakes are also an important source of water supply. They contain large amount of fresh water in storage. Lakes have an upper water surface exposed to the atmosphere and no perceptible gradient with respect to a level surface of reference. In fact lakes are natural depressions with floors below the altitude of the water table and these depression have been created by faulting and erosion by wind and ice sheets. Direct runoff of precipitation and seepage of groundwater maintains lakes throughout the year. Lakes which are situated in high altitude contain almost soft water.

iv) Reservoir: Reservoir are important source of water supply specially in areas where seasonal imbalance of gross water is very high. In such areas where the total flow of a stream or river in a year is sufficient but decreases in dry season the excess water, during monsoon can be stored in a storage reservoir.

Ground Water

Layers of different types of material like limestone, sandstone, sand, clay, gravel and shale are situated below the ground. Some of these material are non porus and water cannot percolate through them. So they do not carry any water. Sand and gravel are pervious and allow water to pass through them. So they contain quantities of water inside. The pervious and impervious layers are situated one over the other. The stratum of earth is usually pervious and is known as the top layer.

That portion of rain water which is absorbed by the earth is called ground water and is the source of underground supplies obtained from different types of wells. Shallow wells achieved water from the top layer. Though the top contains large quantities of water, yet it is not pure because it has travelled only a very short distance. Therefore it is not fully filtered.

Often over the pervious layer occurs the upper impervious one which acts as a deep seated aquifer which recharged by indirect percolation from the surface. This deep seated water is generally purified as has filtered through thick belt of sediments.

Water is continuously flowing through these strata from one end to the other. The part of the soil through which this lateral flow takes place is termed as the zone of saturation and this water is called ground water. Different sources of ground water supply are enumerated below:

i) Springs: Springs are mainly found in hilly areas where the subsoil watertable gets exposed on the slope of the hills. As the watertable is exposed on the slope, water comes out in the form of a spring. There are two types of springs.

1. Surface Spring
2. Deep Seated Spring

A deep seated spring is formed in a particular situation when a pervious layer which is enclosed between two impervious strata is exposed.

Formation of Spring: Springs are formed under two different conditions.

a) Due to the exposure of water bearing soil.

b) The second condition is obtained when a layer of rock lying over an aquifer contains faults just near the ground surface.

When water flows under gravity from the exposed surface it forms a gravity spring. When it comes to ground surface under pressure through a fault in the upper impervious stratum, it is termed as artesion spring.

ii) Shallow Wells: Shallow wells are dug in the top layer of the earth. These wells obtain water from the subsoil water-table. They are also called open or dug wells.

Shallow wells contain poor quality of water as they invariably obtain their supply by direct percolation and sometimes get discharges from soak pits and nalas etc. which pollutes the water.

iii) Artesian Wells: They are formed when an aquifer is enclosed between two impervious layer with the outcrop so high above the site of the well that the hydraulic gradient line is above the ground surface. It is usually formed in a valley and when boring is done in top layer, water which is under pressure rises up and flows out with great force. The quality of water from artesian wells is the same as that of tube-well water.

USE OF WATER RESOURCE

Water is a natural resource which is most universally and constantly in demand. With the rapid growth of population, the need for utilisable water for augmenting food production, the need for municipal water for urbanised population and the need for industrial water have assumed greater and greater importance. Therefore, the requirements for utilisable water has increased manifold and it is expected that by 2000 A.D. the demand will be substantially more than what it is today.

Water is a vital resource and is essential for all types of economic activities. Water that reaches population centre is put to greatest use. Apart from public water supply, water resources will also be increasingly called upon to bear the burden of such diverse activities as irrigation, flood control, hydro-electricity and recreation etc. Some of these demands of water are listed below.

Water Resources Project

No.	Purpose	Works involved
1.	Public water supply	Dams, reservoirs, wells, conduits, pumping stations, treatment work, desalting plant distribution system.
2.	Irrigation	Dams, wells, reservoirs, canals, pumping stations, desilting works, distribution system.
3.	Flood control	Dams, regulatory reservoirs, levees, floodwells, channels, pumping stations, zoning, flood forecasting.
4.	Drainage	Ditches, tile drains, levees, pumping stations, soil treatment, culverts.
5.	Hydroelectricity	Dams, reservoirs, penstocks, power plants, tunnel and shafts.

6.	Navigation	Dams, reservoirs, canal locks.
7.	Pollution and safety control	Regulatory reservoirs, treatment facilities, barriers, ground-water recharge facilities.
8.	Rivers and basin conservation	Soil conservation practices, head water control structures fish ladders and hatcheries, land management practices.
9.	Recreation	Reservoirs and canals with access for fishing, boating and scenic areas.[1]

Irrigation consumes a major portion of water resource in India. Throughout the drier parts of the country there is a great demand for water to be used in irrigation. To provide such water highly expensive dams and water diversion projects have been built and are being built in many places.

Industrial use of water reaches immense proportions in industrial centres. In an industrial centre demand on quantity and quality are very high. Demand of water for cooling is very high because it is the cheapest available

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1 Taylor, A.J. (ed.), Climatic Resources and Economic Activity, London, 1974, p.136.

substance for the transfer of heat. Industrial processing often requires high quality water, but the nature of each individual product is critical. Water which is used in a product needs to be very pure, especially in drinks, food and pharmaceutical industries. Some industries such as cement, iron and steel and paper industries require very high water input per unit of product output.

Use of water for electricity has assumed greater and greater importance, because it has an advantage over fossil fuels (coal, petroleum, and natural gas), as a source of power in that it is a renewable resource. For those areas, which have not yet developed their water power potential and are poorly endowed with coal and petroleum, hydroelectricity would bring great gains in living standard.

The demand of water for various purposes has grown enormously. Therefore optimum use of water resource is necessary. Rate of water consumption per person serve as an index of the stage of industrialization. The coming industrialization of the world, coupled with the doubling of the present world population, will undoubtedly produce shortages unless the available supplies can be correspondingly increased.

PROBLEMS IN WATER RESOURCE UTILISATION

Problems are integral part of progress. With the growth of civilisation man creates new problems. It is true in the case of water resource also. Decrease in water table, land subsidence from excessive groundwater witndrawl, problem of waste disposal and pollution of water resource are the main problem in water resource utilisation.

Decrease in Water Table

With the help of powerful pumps man has seriously depleted water resource. Water table is continuously decreasing in some areas due to the high rate of pumping. Rate of draft is comparatively high than the rate of recharge.

A decrease in water table affects stream flow adversely. The year-round flow of many smaller stream is sustained by groundwater seepage. If the water table goes down permanently below stream level, the stream will contain water only in rainy season, when water reaches the stream directly by over land flow.

The problem of decreasing water table can be solved by artificial recharge.

Subsidence of the Ground Surface

Subsidence of the land surface due to the excessive groundwater withdrawl is an another serious problem. For the solution of problem recharge wells can be drilled to inject water into the aquifer.

Problem of Water Pollution

The problem of water pollution is a global problem. The problem is more severe in developing nations.

Water pollution cannot be confined to the national boundaries. A state cannot ban the entry of pollutents into the river from a foreign territory. Almost all the oceans are becoming universal sewers. Increasing amount of phosphate from various sources in surface water causes over growth of algae which on their death pollute surface water. Pollution adversely affects the resource value of water. The principal sources of water pollution can be discussed under three categories: municipal, industrial and agricultural sources.

1) Municipal Sources: Sewer leakage, the disposal of solid and liquid wastes can introduce high concentration of nitrate, organic chemicals, viruses, bacteria and inorganic chemicals in water resource. Disposal of waste in water

body causes. Amoebic dysentery and other gastrointestinal diseases. Apart from the health hazard, disposal of waste in watercourse creates other problem. Organic wastes decomposes in water and this process use large quantities of oxygen. Due to the high concentration of organic wastes oxygen may be exhausted and aquatic life destroyed.

This problem can be solved by the instalation of sewage disposal plants. In these plants solid organic matter is seperated from the liquid through various processes such as washing, skimming and settling process. Besides this sewage effluent can be used for industrial processes. By this method demand for fresh water for industrial processes will be reduced to a considerable extent and pollution will be also mitigate.

2) Industrial Sources: With the growth of industries rate of water pollution is also increased. Water that leaves an industrial town is generally highly contaminated. Disposal of wastes from food-processing industries and canning industries cause high concentration of organic matter in the surface water. Lumber mills and other industries also have water-borne wastes which are highly charged with organic materials and can cause serious stream pollution. Chemical industries, tanniers and mines have waste

water containing highly toxic chemicals which can render large streams unfit for any further use.

3) Agricultural Source: Approximately two third of the water applied for irrigation is consumed by evapotranspiration and remaining part of it enters into groundwater reservoir. Irrigation causes salinity because water which is used for irrigation derived different salts from fertilizer. Irrigation return flow can be the major cause of ground-water pollution in arid and semi-arid regions.

Fertilizers are partly absorbed by plants and remainder reaches the water table. Fertilizers are compound of nitrogen, phosphorus and potassium. Phosphorus and potassium seldom constitute a pollution problem but nitrogen is a primary fertilizer pollutent.

The problems which have been mentioned above are the main problems of water resource utilisation. Though man has created these problems yet they can be solved with the help of science and technology, imagination and power of ready invention.

CHAPTER III

GROUNDWATER

Fresh water is one of our principal resources and is vital for every type of economic activities. The largest source of groundwater lies underground. Groundwater can be defined as the water that percolates through the interstices of the surface layer of the earth and accumulates in subsurface aquifers.

Waltz has defined groundwater in these words, "Groundwater is that water which occurs beneath the surface of the earth within saturated zones where the hydrostatic pressure is equal to or greater than atmospheric pressure".[1]

ORIGIN OF GROUNDWATER

Origin of groundwater may be traced in the hydrologic cycle. The cycle involves the total earth system: atmosphere, hydrosphere, and lithosphere. The activities of the hydrologic cycle take place from an average depth of at least a half mile in the lithosphere to

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1 Chorley, R.J. (ed.), Water, Earth and Man, London, 1969, p.259.

a height of about 15 km in the atmosphere. The hydrologic cycle begins with the water of the oceans. Precipitation is the source of all types of fresh water supply. Precipitation which falls upon the earth is partly absorbed by the earth and major part of it flows into the streams and river. That portion of precipitation which is absorbed by the earth is mainly detained in the plant zone and remaining part of it reaches below the plant root zone. That portion which is detained in the plant zone is drawn back to the surface by soil capillary action or due to plants transpiration. Therefore only that part of precipitation which reaches below the plant root zone enters the groundwater reservoirs due to the influence of gravity.

There are three sources of groundwater:

1. Meteoric Water: it falls from the atmosphere as rain, snow, hail and sleet.

2. Connate Water: it occupies the intergranular space of sediments during the deposition and remains entrapped.

3. Magmatic Water: juvenile or magmatic water is the stream derived from the deep seated magmas. This type of water generally occurs where volcanic activities take place.

OCCURRENCE OF GROUNDWATER

Various types of geologic formations contain groundwater. Unconsolidated formation is the main source of groundwater supply. 90 per cent of the aquifers are situated in unconsolidated formations. Water bearing capacity of unconsolidated formation is higher than that of consolidated formation. Unconsolidated formation consists of higher rate of permeability, specific yield and recharge than that of consolidated formation.

On the basis of origin and deposition unconsolidated formations can be divided into various categories: alluvium, sand and gravel.

Hydrogeologic Properties of Unconsolidated Formations

Porosity, permeability and specific yield are the prominent hydrogeological properties of unconsolidated formations.

Porosity: It is the percentage of void space to the total volume of mass. If α is the porosity then $\alpha = \frac{100W}{V}$

'W' is the volume of water required to fill all the pore spaces.

'V' is the volume of formation.

Representative porosity ranges for unconsolidated formation are given below:

Table I

Representative Porosity Ranges for Unconsolidated Formation

Material	Porosity per cent
Soils	50-60
Clay	45-55
Silt	40-50
Medium to coarse mixed sand	35-40
Uniform sand	30-40
Fine to medium mixed sand	30-35
Gravel	30-40
Gravel and sand	20-35

Permeability: The laboratory (standard) coefficient of permeability is defined as the flow of water at 16^{o}C in gallons per day through a medium having a cross section area of 30 cm^{2} under a hydralic gradient of 30 cm. The field co-efficient of permeability kf is defined as the flow of water gallons per day through a cross section of aquifer 30 cm thick and 1.5 km wide under a hydraulic gradient of 30 cm/1.5 km at field temperature.

Specific Yield: Specific yield is a fraction of the porosity of an aquifer. Specific retention shows the percentage of the volume of water it will retain after saturation against the force of gravity to its own volume.

$$Sr = \frac{100\ Wr}{V}$$

Where

'Sr' is the specific retention

'Wr' is the volume occupied by retained water

'V' is the gross volume of the formation. The water which can be drained is expressed as the specific yield (Sy)

$$Sy = \frac{100\ Xy}{V}$$

'Wy' is the volume of water drained by gravity.

Table II

Representative specific yields of unconsolidated formation

Material	Specific yield per cent
Gravel	25
Sand, including sand and gravel and gravel and sand	20
Fine sand, hard sand and light sand	10
Clay and gravel, gravel and clay, cemented gravel and related deposits	5
Clay silt and sandy clay	3

<u>Formation of Aquifer</u>: An aquifer is a layer that contains free water. A rock formation wether it is consolidated or unconsolidated if it contains significant amount of water may be defined as an aquifer. There are various type of aquifer which are different to each other in variety and shape. Aquifers which are situated in alluvial deposits range in size from fine sand to gravel and boulders. An aquifer serves both as a storage reservoir and a network of conduits.

Classification of Aquifers: Aquifers may be classified as follows:

1. <u>Unconfined Aquifer</u>: In unconfined aquifer groundwater possesses a free surface open to the atmosphere. Water-table serves as the upper surface of the zone of saturation in such types of aquifers. Any increase or decrease in water-table changes the thickness of the zone of saturation. Such aquifers are known as non-artesian aquifers.

2. <u>Confined Aquifers</u>: Confined aquifer is one in which groundwater is retained between relatively impermeable strata. Groundwater in such types of aquifers occurs under pressure greater than the atmospheric pressure. It is also known as artesian aquifer. Confined aquifers may be classified as leaky and non-leaky aquifers.

a) A leaky aquifer is one in which groundwater in aquifer is confined by aquitards.

b) A non-leaky aquifer is one in which groundwater is confined by aquicludes.

3. Perched Aquifer. It exists above unconfined aquifer where an impermeable strata of small areal extent exists.

Distribution of Groundwater

Knowledge of occurrence of groundwater needs a study of the vertical distribution of water in geologic formation. Groundwater confined in the interstice of rocks is vertically distributed in two zones.

i) Zone of aeration
ii) Zone of saturation

i) Zone of Aeration: Where the interstices are only partly saturated with water they constitute the zone of aeration. The zone of aeration can be sub-divided into three belts.

i) The belt of soil-water
ii) The intermediate belt
iii) The capillary fringe

These belts are varied in thickness and their limits cannot be defined strictly by physical differences in the earth materials. A transitional zone exists between two belts.

a) The Belt of Soil-Water: Water in this belt exists at less than saturation except temporarily when excessive water reaches the ground surface as from rainfall or irrigation. The belt of soil-water extends from the ground surface through the major root zone. Its thickness varies with soil type and vegetation. The amount of water present in this belt depends primarily on the recent exposure of the soil to moisture. The belt of soil-water may contain water in excess of capillary water from rainfall or irrigation; this gravitational water drains through the soil under the influence of gravity.

b) Intermediate Belt: The intermediate belt is situated between the belt of soil water and the capillary fringe. Water that enters the intermediate zone continues its downward movement under the force of gravity. The intermediate zone holds suspended water by molecular attraction and capillarity. In this zone capillarity gains more importance than molecular attraction. This zone is characterised by ample variation in thickness.

c) The Capillary Fringe: The capillary fringe occurs immediately above the zone of saturation. In this zone capillary force acts against the force of gravity and due to this force it contains water above the zone of saturation. The thickness of capillary fringe ranges between 2 metre to a fraction of 2 cm in silt, clay and sand or gravel respectively.

ii) Zone of Saturation: This belt exists below the capillary fringe. In this zone all the openings are completely filled with water. "The part of the soil through which lateral flow takes place is termed as the zone of saturation"[1].

The thickness of the saturation belt varies greatly from few metre to many hundreds metre. Various factors such as the availability of pores in the formation, local geology, recharge and movement of water govern the thickness of the zone of saturation.

GROUNDWATER RECHARGE

For the assessment of groundwater resources recharge rate must be estimated. Major sources of recharge

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1 Singhal, R.P., A Text Book on Water Supply Engineering, Patiala 1958, p.4.

to aquifers are direct precipitation or percolation of stream water. Recharge from direct precipitation is very irregular. Several factors such as topography, soil moisture content, vegetative cover, character and thickness of soil and other deposits, seasonal distribution of rainfall and its intensity, the depth to water-table determine the amount of precipitation that reaches the zone of saturation.

Recharge involves the vertical downward movement of groundwater under the influence of vertical head differentials. Permeability and thickness of deposits govern the quantity of vertical leakage.

Artificial Recharge

Artificial recharge means enhancing the groundwater storage by the infiltration of surface water into underground formation. In the words of Walton "artificial recharge may be defined as the practice of increasing, by artificial means, the amount of water that enters a groundwater reservoir".[1]

The practice of artificial recharge is increasing day by day. By the use of artificial recharge technique we can maintain or enhance the natural groundwater as an economic resource. Coordinated operation of surface and

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1 Walton, W.C., Groundwater Resource Evaluation, New York, 1970, p.364.

groundwater reservoirs is also possible with the help of this technique. This method can be helpful for providing a localized subsurface distribution system for established wells.

Recharge Methods

A variety of methods have been developed including water spreading, recharging through basins, stream channel, ditches and furrows, pits and wells and pumping to induce recharge from surface water bodies. Choice of a particular method depends upon several factors such as local geologic, topographic and soil conditions, the quantity of water to be recharged and the ultimate water use.

The most widely practical method is water spreading. In this method water is released over the surface in order to augment the quantity of water infiltrating into the ground and percolating to the water table.

The spreading method can be classified into basin, ditch and furrow, stream channel, flooding and irrigation.

1) Basin Method: Water may be recharged by releasing it into basins, which are formed by excavation, or by construction of dikes or dams. Where local runoff is being recharged a single basin will be enough, but where stream

flow is being diverted a series of basin becomes necessary. The basin method is the most desirable method of recharge due to its feasibility and ease of maintenance.

ii) Stream Channel Method: Water spreading in a natural stream channel involves operations that will increase the area and time over which water is recharged from a naturally losing channel. Stream channels can be improved by leveling, widening and ditching to increase infiltration into ground-water reservoirs.

iii) Ditch and Furrow Method: The ditch method is adaptable to irregular terrain. In this method water is distributed into shallow, flat bottomed ditches and furrows. There are series of ditches and furrows to obtain maximum water contact area. Gradient of ditches should be sufficient to carry suspended material through the system.

Flood Method

In flat topography water can be diverted to spread over a large area. Highest infiltration rates occurs on areas with undisturbed vegetation and soil covering.

Recharge Well Method

Such wells admit water from the surface to aquifers. Well recharging is the most favoured method in urban areas due to the economy of space. Clogging of aquifers due to suspended materials, microorganism and by air binding, is the worst problem in this method because it reduces the permeability of aquifers. Chemcial reactions may occur due to the chemical constituents of the recharge water which may differ from the normal groundwater.

QUALITY OF GROUNDWATER

The quality of groundwater is just as important as its quantity. The chemical, physical and bacterial characteristics of groundwater determine its usefulness for various purposes such as domestic, irrigational and industrial purposes.

Chemical analysis determines the concentration of inorganic constituents in groundwater. Physical analysis evaluates colour, odour, turbidity and temperature of groundwater, while bacterial analysis includes tests to detect the presence of coliform organisms.

CHEMICAL ANALYSIS

Chemical analysis determines the concentration of calcium, magnesium, sodium, and potassium (positively charged ions) and the anions (negatively charged ions), including sulphate, chloride, fluaride and nitrates.

Calcium and magnesium cause almost all the hardness of water. Total hardness of water can be divided into two groups: carbonate and non-carbonate.

Carbonate hardness is called temporary hardness, because it can be removed by boiling. It consists of that portion of calcium and magnesium that would combine with bicarbonate and the small amount of carbonate.

Non-carbonate hardness is known as permanent hardness. It is caused by that amount of calcium and magnesium that would combine with sulfate, chloride and nitrate ions that are present.

A hardness of 50 to 150 ppm is considered acceptable.[1]

Specific Electrical Conductance

Chemically pure water has a very low electrical conductance. Values of specific conductance for groundwater are reported in millionths of mhos or 'micromhos'. Amount of dissolved mineral in water determines its specific conductance. With the increase of temperature conductance of a water solution also increases.

1 Brigg, G.F. and Fiedler, A.G. (ed.), Groundwater and Wells, Minnesota, 1983, p.65.

Total Dissolved Solids

Total dissolved solids are directly related to electrical conductivity or salinity. According to ICMR minimum and maximum permissible limits of T.Ds in potable water are 500 mg/l and 1500 mg/l respectively. Water with more than 1500 mg/l of dissolved solids usually contains minerals, which make the water unsuitable.

Hydrogen Ion Concentration

Hydrogen concentration in groundwater shows its alkalinity. Hydrogenation concentration is expressed by its pH value. A pH value of 7 shows a neutral solution while a pH value less than 7 indicates an acid condition while a pH value greater than 7 indicates alkaline solution.

Calcium

Calcium is an essential element of groundwater. Water having 100 mg/l of calcium is harmless. The common sources of calcium in groundwater are apatite, fluorite, and various members of fedspar, amphibole, and pyroxene groups in igneous and metamorphic rocks, and dolomite, gypsum, aragonite and anhydrite in sedimentary rocks.

Sodium

It is a metal of alkali metal group. Sodium does not contribute to the hardness of water. However, groundwater containing considerable amound of sodium, bicarbonate or sodium carbonate are alkaline. The primary sources of sodium in groundwater is palagioclase feldspar and the solution of halite is also important. Sodalite, natrolite, jadeite are other source of sodium.

Magnesium

It is one of the constituents responsible for hardness of water. Groundwater in contact with sedimentary rocks derive most of their magnesium from dolomite. Angite, olivine and hornblende in igneous rocks and tremolite, serpentine and diposide in metamorphic rocks are the main sources of magnesium.

Silica

Silica does not contribute to the hardness of water. Main source of silica in groundwater is the decomposition of mineral silicates which are present in many rocks. 20 ppm concentration of silica in groundwater is common.

Sulfate

Sulfate in groundwater is derived from gypsum and the oxidation of pyrite which is iron sulfide. Magnesium sulfate and sodium sulfate if present is present in sufficient quantities cause bitter taste.

Nitrate

Most nitrate in groundwater is derived from organic sources or from industrial and agricultural chemicals. Nitrate concentration in groundwater greater than 45 ppm is undesirable for domestic purposes.

Dissolved Gases

Common dissolve gases include oxygen, hydrogen sulfide, carbon dioxide, nitrogen, sulphur dioxide and ammonia. Among these gases first three gases have paramount importance in groundwater development. Common sources of these gases are the atmosphere and decaying organic matter.

Hydrogen Sulfide

Hydrogen sulfide in groundwater can be identified by its rotten egg odour. Sulfate reducing bacteria change sulfate to hydrogen sulfide. Due to presence of hydrogen sulfide water becomes usually corrosive.

Carbon Dioxide

The presence of carbon dioxide in groundwater is especially significant where calcium and bicarbonate are in solution.

PHYSICAL ANALYSIS

Temperature, colour, turbidity, odour and taste are evaluated in physical analysis of groundwater.

Temperature

Temperature of groundwater in a region is affected by many things such as rock type, elevation, precipitation and cloudiness. Shallow groundwater temperature may also be affected by the type of overlying environment. 'Below shallow depths, groundwater temperature increase approximately 1°C for each 100 feet of depth in accordance with the geothermal gradient of the earth crust'.[1]

Colour

Colour in groundwater is caused by dyes derived from decaying vegetation, iron and manganese. Coloured water is harmfull and may adversely affect industrial processes.

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1. Walton, W.C., op. cit., 1970, p.451.

Turbidity

Velocity of the water and soil type of that region over which water has run determine the character and amount of turbidity. Turbidity is due to suspended materials, usually sand dirt and silt or other solids and growth of algae and plankton. Groundwater is normally clear because turbidity has been filtered out due to slow movement of water through the different layers of soil.

Odour and Taste

These aspects of groundwater are derived from dissolved gases, mineral matter, decaying organic matter, living algae and other microscopic organism. Dissolved $H_2{}^S$ causes bad odour in water. Three types of odours are found in water viz., aromatic, grassy and fishy. "Aromatic odours are evolved by the diatoms -- Asterionella, Cyclotelle, Meridion and Tabellaria; grassy odours by Cyanophyceae-Anabern, Rivularia and fishy smell by Chlorophyceae-Volvox, Eudorina, Pondorina and by Protozoa-Uroglena, Barsaria, Peridiniam".[1]

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1 Awasthi, S.C., Quality of Water in Relation to its Use, Indian Mineral, Vol.28, No.3, Calcutta, 1974, p.27.

BACTERIAL ANALYSIS

Two types of organic impurities may be found in water: animal and vegetable, while animal impurities are highly dangerous, vegetable impurities are not so dangerous. Animal impurities cause all types of water borne bacterial infections. Bacteria, protozoa, warms, viruses and fungi are prominent organisms in water.

Bacteria

They can be divided into two groups:

i) Higher bacteria and
ii) Lower bacteria

Iron and filamentous sulphur bacteria are important in first the group. Baggited is the representative of sulphur bacteria.

Soil bacteria are most common in surface water. Aerobic, spore producing genus bacillus are commonest in surface water. Crenothrix polysposa is important bacteria in groundwater. Colouration in drinking water is possible due to this bacteria.

Protozoa

It is an unicellular micro organism. Among four sub-phyla Sarcodina, Infusaria Sporozoa and Mastigophora, it is Mastigophora which causes trouble.

Warms

There are three aquatic groups:

a) The annalids or the aquatic earthwarm

b) The Trochal warm

c) The Nomatodes (Nemathelminthes), or the roundwarm

Virus and fungi also cause several disease such as epidemic jaundice and poliomyelitis.

WATER QUALITY CRITERIA

Utility of groundwater for a particular purpose depends upon the standard of acceptable quality for that use. Standard of acceptable quality for drinking water, industrial water and irrigation water vary widely. The quality of water supply is a matter of paramount importance. The chemical quality of water plays a very important role in its utilization. Use of groundwater can be classified into three groups: i) Domestic use, ii) Agricultural use, iii) Industrial. Quality limits of water supplies for drinking water and for industrial and agricultural purpose will now be described.

Quality of Water for Drinking Purposes

Water must be potable and wholesome for drinking purpose. It should not contain poisonous substances, excessive amount of mineral and organic matter. Water must be free from colour, odour, taste and turbidity. It should be aerated and moderate in temperature. Water which contains poisonous substances is not fit for drinking purpose. Fluorine, selenium, arsenic and boron are poisonous substances. Arsenic and boron are rarely found in natural water while fluorine and selenium are common. Other poisonous substances such as copper, iron, lead and zinc may be derived from distribution system. Iron, copper and zinc discolour water. Lead causes poisoning which is known as plumbism.

Excessive amount of following substances in groundwater provides ground for rejection of water supply.

Arsenic	(As)	0.5 mg/liter
Barium	(Ba)	1.0
Cadmium	(Cd)	0.01
Chromium (Lexanalent)	(Cr^{6+})	0.05
Cyanide	(CN)	0.2
Lead	(Pb)	0.05
Selenium	(Se)	0.01
Silver	(Ag)	0.05

Quality of Water for Agricultural Purposes

Suitability of groundwater for irrigation depends upon various factors such as total concentration of soluble salts, relative proportion of sodium to other cations, concentration of boron or other elements that may be toxic.

Salt may harm plant growth physically by limiting the uptake of water or chemically by metabolic reactions. Salts may cause changes in permeability, aeration and soil structure. It can affect plant growth also.

Sodium concentration is important in classifying an irrigation water, because sodium reacts with soils to reduce its permeability. Higher concentration of sodium salts develops alkali soils in which little or no vegetation will grow.

Table III

Sodium Hazard

S.A.R.	Type of Water	Classification of Water
0 - 10	Low sodium water	Suitable for almost all soils
10 - 18	Medium sodium water	Suitable only for coarse textured or organic soils with good permeability
18 - 26	High sodium water	Harmful
over 26	Very high sodium water	Unsatisfactory

S.A.R. Sodium adsorption ratio

Born is necessary in very small quantities for normal growth of all plants, but in larger concentrations it becomes toxic.

Table IV

Boron Hazard

Less than 0.7 ppm	Safe for sensitive plants
0.7 - 1.5 ppm	Marginal
More than 1.5 ppm	Unsafe for normal crops

Salinity in groundwater also determines its quality in relation to irrigation.

Table V

Salinity Hazard

Conductivity in micromhes/m. at 25°C	Salinity	Classification of water
	Low	Suitable, can be used for irrigation of most crops on most soil
250	Medium	Satisfactory
750	High	Injurious, needs careful management and favourable drainage
2,250	Very high	Not suitable

High proportion of magnesium and sulfate or sodium is very undesirable for stock use. A concentration of more than 0.5 ppm. selenium in water could be very poisonous to animals.

Quality of Water for Industrial Purposes

Quality requirements of water used in different industrial processes vary widely with the manufacturing process and with the quality of the goods to be produced. Even, within each industry, criteria cannot be established, instead, only recommended limiting values can be stated. Salinity, silica and hardness are three parametres that usually are important for industrial water.

Fluctuation of water temperature can be trouble - some. Therefore groundwater supplies are preffered to surface water supply which commonly plays seasonal variation in physical and chemical quality.

CONSERVATION AND MANAGEMENT OF GROUNDWATER RESOURCES

Groundwater is one of the earth's most widely distributed and most important renewable resource. In recent years the use of groundwater has grown enormously. Therefore groundwater conservation is necessary. In some areas groundwater is being pumped out of aquifers faster than natural recharge. Due to higher pumpage rate water table declines gradually. The term 'water mining' is often being used to refer to these situations.

Some persons believe that groundwater conservation means only use on a sustained yield basis. Continued overdraft causes sharp decline in water table. Some people think that proper use of groundwater without undue waste is conservation and they believe that it is absolutely right to utilize the water for economic development of the area as long as it lasts.

The most serious problem of groundwater shortage occurs in areas where water is pumped out faster than the rate of recharge of the reservoir. Under these conditions reservoirs will be emptied. Confined aquifers that are recharged by influent seepage from streams and by direct infiltration of precipitation may be drawn upon safely upto the limit of natural or induced recharge.

For the fulfillment of our needs optimum development of groundwater is necessary which is possible in two ways:

i) For those aquifers which are readily recharged from the surface, average pumpage should not exceed average recharge.

ii) For deep artesian aquifers with little natural recharge average pumpage may exceed recharge but this must be carefully managed.

Some corrective measures for groundwater conservation are given below:

i) Prevention of waste
ii) Reclaiming of used water
iii) Artificial groundwater replenishment by surplus stream water
iv) Reduction of pumping from production wells

The disparity between draft and natural replenishment may be reduced by increasing the replenishment artificially, which is a more desirable solution to the problem than the alternative of restricting the withdrawl of groundwater.

Use of water is increasing day by day. Increased used by industry and agriculture are placing an extra burden on the country's water resources. Due to erratic supply of surface water people have tended to rely on groundwater as a more reliable source. Exploitation of groundwater as a principal source of supply has been enormously increased. The use of groundwater for irrigation and industrial purposes has been increased as it is free from bacteria and constant in temperature. Excessive utilisation of groundwater has created a hiatus between supply and demand and has thus created new water problems such as an imbalance in the hydrologic cycle. Utilisation of water without a proper understanding of all possible effect will amount to irrational exploitation. Contrary to this the use of water with knowledge of probable effects and with planning may minimize the adverse effects. This can be termed water management. Management objectives involve geologic, hydrologic, economic legal, political and financial aspects. Good management of groundwater resources depends upon knowledge of basic water facts. Management of groundwater involves planning in terms of an entire groundwater basin.

In plans for river basin development groundwater has been neglected, yet plans for river basins may affect the groundwater reservoir. In groundwater basin flood water can be used as an artificial means of recharge.

The main objective of groundwater management is to obtain the maximum quantity of water to meet predetermined quality requirement at least cost. There is a gap between draft of water and basin's natural recharge capability. This tendency can be checked by a management plan otherwise groundwater resources could be depleted.

Before the development of groundwater in a basin an investigation of groundwater is necessary. In general, investigation involves evaluation of quantity and quality of groundwater resources, impact of human activities on the quantity and quality of groundwater. In a given basin optimal beneficial use can be obtained by conjunctive use, which involves the coordinated and planned operation of both surface water and groundwater resources to meet water requirements in a manner whereby water is conserved.

During periods of above normal precipitation, surface water is utilised to the maximum extent and also artificially recharged into the ground to enhance ground storage and raise groundwater level and during drought periods surface water are supplemented by pumping groundwater. Conjunctive use of groundwater does require careful planning to optimize use of available surface water and groundwater resources. Groundwater basin management is highly technical and requires competent personnel, detailed knowledge of the hydrogeology of the basins, records of pumping and recharge rates and updated information on groundwater levels and quality. In groundwater management only the knowledge of hydrologic facts is not sufficient. We should know what the demand is and what the future demand may be in a given area. What will be the effects of withdrawl and use of water upon the groundwater reservoir? There are several measures which, if undertaken on a large scale would conserve the supply of groundwater. Natural replenishment can be increased by increasing the infiltration rate into the soil or stream beds. Reduction of evaporation from reservoirs and even of transpiration by certain methods of soil treatment holds some promise. Surplus surface water could be stored in underground reservoirs. By sound groundwater management water can be conserved for a long period.

CHAPTER IV

UTTAR PRADESH : A GEOGRAPHICAL INTRODUCTION

The territorial limits of Uttar Pradesh extend between $23^{\circ}45'$ and $31^{\circ}30'$ North latitudes and $77^{\circ}00'$ East longitude. It covers an area of about 2,94,413 sq. km. Located in north India, Uttar Pradesh is bounded on north by Himachal Pradesh, Tibet (China) and Nepal on east by Bihar, on south by Madhya Pradesh and on west by Rajasthan, Haryana and Delhi. Its ranking among the Indian states in terms of area is fourth, the first three being Madhya Pradesh, Rajasthan and Maharashtra, The state coveres nearly nine per cent of the total area of the country. The State of Uttar Pradesh is the home for 11,08,62,013 people as per the 1981 census. This makes Uttar Pradesh is the most populus state in India. The average density of population per sq. km in 1981 was 377. Agriculture is the main occupation of the state and 70 per cent of its population is engaged in this activity.

HISTORICAL BACKGROUND

In 1837 the then Bengal Presidency was divided into two parts one of which became the Presidency of Agra.

In 1836 the Agra area was styled the north-west province and placed under a Lieut. Governor. The two provinces of Agra and Oudh were placed in 1877 under one administrator, styled Lieut.-Governor of the North-West Province and Chief Commissioner of Oudh. In 1902 the name was changed to "United Provinces of Agra and Oudh", under a Lieut.-Governor and the Lieut.-Governorship was altered to a Governorship in 1921. In 1935 the name was shortened to 'United Provinces'. After independence, the princely States of Rampur, Banaras and Tehri-Garhwal were merged with United Provinces. In 1950 the name of the United Provinces was changed to Uttar Pradesh.

ADMINISTRATIVE DIVISIONS

Being a very large state, for the purpose of administration Uttar Pradesh is divided into 11 administrative divisions. The districts covered under each division are given in Table VI.

Geology

Structurally, Uttar Pradesh forms a part of the Indo-Gangetic Plain which extends between Himalayan chain and Peninsular India. The great plain consists of alluvium deposited through geologic ages by the Himalayan rivers.

Table VI

Administrative Division of Uttar Pradesh

Division		Districts
I.	Meerut	Bijnor, Bulandshahr, Ghaziabad, Meerut, Muzaffarnagar, Saharanpur
II.	Agra	Agra, Aligarh, Etah, Mainpuri, Mathura
III.	Bareilly	Bareilly, Budaun, Moradabad, Pilibhit, Rampur, Shahjahanpur
IV.	Allahabad	Allahabad, Etawah, Farrukhabad, Fatehpur, Kanpur, Kanpur (Dehat)
V.	Jhansi	Banda, Hamirpur, Jalaun, Jhansi, Lalitpur
VI.	Varanasi	Ballia, Ghazipur, Jaunpur, Mirzapur, Varanasi
VII.	Gorakhpur	Azamgarh, Basti, Deoria, Gorakhpur
VIII.	Lucknow	Hardoi, Lakhimpur Kheri, Lucknow, Rae Bareli, Sitapur, Unnao
IX.	Faizabad	Bahraich, Barabanki, Faizabad, Gonda, Pratapgarh, Sultanpur
X.	Kumaon	Almora, Naini Tal, Pithoragarh
XI.	Garhwal	Chamoli, Dehra Dun, Garhwal (Pauri), Tehri Garhwal, Uttar Kashi

The nature of the detritus varies from big boulders to silt and clay. The arrangement of the beddings and the general form of the surface indicate that they were laid down in gently inclined layers.[1]

Edward Suess the Austrian geologist suggests that the great plain is a 'fore deep' formed infront of resistant mass of the peninsula when the Tethyan sediments were thrust southward and compressed against them.[2]

S.G. Burrad on the basis of geological data arrived at a totally different view of the origin of this depression. According to him the plain constitutes a rift valley and is bounded by parallel fault on its two sides with the maximum down throw of 20 (32 km) miles/long.[1] This view however, has not been accepted by Indian geologist because it is not supported by sufficient geological facts. A third and more recent view regards this region as a sag in the crust formed between the northward drifting Indian sub-continent in the south and the comparatively soft sediments accumulated in the Tethyan

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1 Jame Geikio, *Earth Sculpture*, London, 1898, pp.40-41.

2 Krishnan, M.S., *Geology of India and Burma*, Madras, 1956, p.529.

3 Burrard, S.G., *On the Origin of the Himalayan Mountains*, Geological Survey of India, Professional Paper No.12, Calcutta, 1912, p.11.

as well as in the connected basins on the north. The crumpling of the sediments resulted in the formation of a mountain system.[1] The depression perheps began to form in the upper Eocene and attained its greatest development during the third Himalayan upheaval in the middle Miocene. Since then it has been gradually filled up by sediments to form a level plain with a very gentle seaward slope.[2] Geological and geodetic data appear to support the view of the northward drift of Indian continent and is more reliable.

The maximum depth of the alluvium is not known. The borehole at Lucknow in Uttar Pradesh is only 1330 feet(405 m) deep and which has not touched the rock bottom.[3] On the basis of geodetic data, Oldham finds that the depth of the trough lies between 15,000 and 20,000 feet (4575 to 6100 m) towards its northern edge.[4] The thickness of the alluvium increases from west to east.

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1 Wadia, D.N. and Anden, J.B., Geology and Structures of Northern India, Memoirs of Geological Survey of India, Vol.73, Delhi, 1939, p.134.

2 Krishnan, M.S., 1956, op. cit., p.529.

3 Oldham, R.D., The Dead Boring at Lucknow, Records of the Geological Survey of India, Vol.XXIII, p.263.

4 Oldham, R.D., The Structure of Himalayas and of the Gangetic Plain, Memoirs of the Geological Survey of India, Vol.XLII, Pt.II, Calcutta, 1917, p.82.

The pre-tertiary river-borne debris from the Peninsula, later supplemented rather more vigourously by the upper and post-tertiary Himalayan debris, yet to undergo intense compaction, constitute, by and large, the alluvial filling.

The alluvial deposits of Uttar Pradesh can be divided into two groups:

A. Old deposits

B. New deposits

The older deposits of alluvium are known as bhangar, contrary to this the new ones are called Khadar. In respect of their geological age, these deposits correspond with two main divisions of the Quaternary Era, the Pleistocene and the Recent.

Bhangar occupies the interfluvial zones above the general flood limits, the constituents experiencing slow changes. One distinctive character of the bhangar are the nodules of carbonate which of lime known as kankar. In the beds of the Ganga and the Ghaghara, masses of calcareous tufa are often found forming a matrix of conglomerates. The kankar and the calcareous beds have been deposited from the water containing a solution of the carbonate of lime derived from the older rocks of various kinds, or else from fragments of limestone contained in the alluvium.

Patches of saline and alkaline efflorescence the result of gentle slope are also found in bhangar areas. Correspondingly, the gradient of the water-table associated with these gentle slopes is also small. The low gradient leads to a stuggish movement of groundwater as well as to a slow movement of surface water.

The <u>khadar</u> occupies a level lower, than the bhangar. The khadar lands owe their origin to the bhangar lands through the erosine action of the rivers. The khadar contains neither kankar nor reh.

Granite and other crystalline rocks of unfossiliferous sediments forme lower Himalayan zone. The sub-Himalayan zone is composed of sediments mostly of Tertiary age. Sub-Himalayan zone is built entirely of Siwalik sediments. The Siwalik constitute a great thickness of detrital rocks clays and conglomerates. The beds of sand stone and shale are seperated from the Eocene beds of the Lower Himalayas by the 'Great Boundary Fault'. The Eocene beds of the Lower Himalayas have been seperated from Lower Siwaliks by a great thrust known as the 'Main Boundary Fault'.

The lower Himalayan zone is seperated from the Higher Himalayan zone by the 'main central thrust of Himalaya'. The crystalline sheet of the higher Himalayan zone has a simple tectonic feature. The main rocks of this zone are quartzites, magnetites, gneiss, garnet-schists, dioritic amphibolites etc.

Physiography

Despite huge variation, physiographically the State of Uttar Pradesh can be divided into three physiographic units:

1. Himalayan Region
2. Gangetic Plain
3. Bundelkhand and Vindhyan Plateau

1. Himalayan Region

This region constitute a part of the Himalayan chain in the north and covers over 17 per cent of total area and accounts for 4 per cent of total population. The Himalayan region comprises the Himalayan Mountains and their associated foothills. Deep gorges and narrow valleys dissect this mountainous region. Himalayan region can be sub-divided into:

i) Greater Himalayas
ii) Lesser Himalayas
iii) Siwaliks

i) <u>The Great Himalayas</u>: It covers the north-western part of Uttar Pradesh and is known as the Kumaun Himalayas. This high land contains many snow covered mountain peaks such as Trishul (7085.45 m), Kamet (7696.96 m), Nanda Devi (7778 m), and Kedar Nath (6667 m). The Great Himalayas checked the cold air masses from the east.

ii) <u>Lesser Himalayas</u>: Lesser Himalayas are situated on the south slope of Great Himalayas. Ranges of Lesser Himalayas rise to the altitude of more than seven thousand feet. Naini Tal, Mussoorie and Chakrata are situated in this region.

iii) <u>The Siwaliks</u>: Immediately below and between the Beas and the upper reaches of the Ganga stand the Siwalik Hills. The Siwalik ranges have been separated from the main Himalayan ranges by the 'Main Boundary Thrust'. The Siwalik zone has undergone very recent folding and faulting including early Pleistocene thrusting.

2. <u>Gangetic Plain</u>

The Gangetic alluvial plain occupies about 70 per cent of the total area of the state. It with 90 per cent of the total population it is the most populus part of the state. It stretches for about 800 km from east to west and 500 km from north to south between the Himalayan Mountain chain and

Peninsular Plateau. This lowland includes almost level to gently sloping alluvial plain with local depressions of the Ganga and its tributaries. The average elevation of the region is 85 metres above mean sea level in the east at Varanasi and to about 268 metres in the north at Roorkee. In this region average gradient is 0.2 metre per km.

A large part of this plain was a sea-bed in the post-tertiary period. This was filled with Pleistocene alluvial deposits of the rivers of the Indo-Ganga system. It is therefore a very fertile plain. The wide and deeply cut valleys of the rivers are called 'khadars' and the rest of the plains 'bhangars'.

3. Bundelkhand and Vindhyan Plateau

Two small tracts which differ considerably from the main part of the state lie in the south-west and south-east of Uttar Pradesh. The western part of this tract is known as Bundelkhand and the eastern part is called Vindhyan tract. This region covers 13 per cent of the total area having 6 per cent of the total population.

Bundelkhand tract is broken up especially in the south by low rocky hills. The spurs of the Vindhyan Mountains are covered with considerable patches of a riden type of earth known as black soil.

The slope of this region is towards the north-east and the general topography is undulating.

<u>Drainage</u>

The Ganga and the Yamuna are the main rivers of the state and the rest are their tributaries. Yamuna itself is the major tributary of the Ganga. Both Ganga and Yamuna are prennial and have their source in glaciers of the Himalayas.

In the north and north-east the state is drained by the main rivers and their tributaries like Ghagra, Sharda, Sarju, Rapti, Gomti and Ramganga, all of these tributaries emerge from the Himalayas.

In the south-west the drainage is through the rivers Chambal, Sind, Betwa, Ken, Tons, and sone all of which join the Ganga or its tributaries. The Himalayan rivers are more active than those coming from the Vindhyan range in filling up the great plain with silt and they also provide more important source of irrigation and power, since they have perennial supplies of water from the monsoon rainfall supplementel by melting snow.

Climate

The entire state has sub-tropical monsoon climate. In summer, it is dry and hot and in the winter is moderate to severe and not frost free. India lies in the regimes of south-west and north-east monsoon. These directions of the winds are only applicable while they reach the landmass from the Indian Ocean but when these winds enter Uttar Pradesh, the directions become south-easterly and north-westerly, respectively. The reversal of pressure takes place regularly twice a year due to these two prevalent types of winds. During the winter or north-east monsoon period the area is mainly dry. The weather in this season is marked by clear sky, low humidity and extremes of temperature. During the south-west monsoon, the wind blow in the plain from the east towards the west, they are oceanic in origin and are laden with moisture.

The south-west monsoon, enters Uttar Pradesh usually towards the end of June. Since these winds come from the sea, they bring moisture with them, and as they traverse over the land, condensation lessens progressively Uttar Pradesh, therefore gets most of its rainfall in summer.

The pressure gradient during the winter season is very much gentle and the consequently wind force is also weak. On the other hand the excessive heating of the area during summer season gives birth to steep gradients owing to which the wind blows with a strong force.

Temperature

The mean annual temperature in the plains varies from 25°C to 27°C. In the hills and foothills of Uttar Pradesh the mean annual temperature is about 13°C. To the north of the isotherm 25°C which passes through Aligarh, Bahraich and Gorakhpur, the temperature decreases as the latitude increases. To the south of this isotherm, the temperature does not show appreciable decline.

The mean annual minimum temperature in the plains varies between 15°C and 20°C. The mean annual temperature for hilly areas is 10°C.

The mean annual maximum temperature in the plains varies from 30°C to 33°C.

In the hills the minimum temperature reaches much below freezing point in most of the places. In the higher altitude region of the Himalayas, snowfall is a common feature from December to March and some of the higher mountain peaks remain under perpetual snow.

Rainfall

The state receives most of the rainfall through south-west monsoons. The rainy season commences in the later half of June at different dates which are very uncertain. It brings relief by lowering down the temperature gradually which range between 30°C and 40°C during June-October. The relative humidity remains over 70 per cent throughout the rainy season except for June when it averages below 50 per cent. The rainy months account for over 90 per cent of the total annual rainfall. The monsoon rainfall as also the annual rainfall decreases westward as well as southward. Districtwise rainfall normals are given in Table VII.

The average annual rainfall varies between 600 mm and 2000 mm. The Himalayan region gets about 1000 mm. to 2000 mm while the plain area receives from 600 mm to 1400 mm and the southern plateau between 200 mm to 1200 mm.

Acharactenistic feature of rainfall regime is the westward and southward decline in the total rainfall. From a detailed study of the average annual rainfall, the following conclusion can be drawn.

Table VII

Rainfall Normals Uttar Pradesh

District	Coordinates		Annual rainfall normal in millimeter
	Latitude	Longitude	
1	2	3	4
Agra	27°20'	78°00'	664.8
Aligarh	27°54'	78°05'	627.7
Allahabad	25°28'	81°50'	945.5
Almora	29°36'	79°40'	1044.8
Azamgarh	26°03'	83°11'	1060.4
Budaun	28°03'	79°07'	854.2
Bahraich	27°34'	81°36'	1184.6
Ballia	25°44'	84°10'	1103.1
Banda	25°29'	80°21'	969.5
Barabanki	26°54'	81°12'	1061.0
Bareilly	28°22'	79°26'	1076.5
Basti	26°47'	82°43'	1200.0
Bijnor	29°22'	78°08'	975.2
Bulandshahr	28°24'	77°52'	653.7
Dehra Dun	30°19'	78°02'	2048.1
Deoria	26°30'	83°47'	1058.4
Etah	27°34'	78°41'	681.2
Etawah	20°47'	79°01'	753.2

contd......

Table VII (Contd.........)

1	2	3	4
Faizabad	26°47'	82°08'	1050.2
Farrukhabad	27°22'	79°38'	832.4
Fatehpur	35°56'	80°50'	861.9
Garhwal	30°09'	78°47'	1302.9
Ghazipur	25°35'	83°34'	1070.6
Gonda	27°08'	81°56'	1219.0
Gorakhpur	26°45'	83°22'	1248.0
Hamirpur	25°57'	80°08'	865.9
Hardoi	27°24'	80°08'	971.2
Jalaun	26°08'	79°20'	785.6
Jaunpur	25°45'	82°41'	1031.6
Jhansi	25°26'	78°35'	943.9
Kanpur	26°28'	80°21'	804.9
Lakhimpur Kheri	27°54'	80°48'	1070.0
Lucknow	26°51'	80°56'	1015.9
Mainpuri	27°14'	79°02'	740.5
Mathura	27°30'	77°41'	544.3
Meerut	29°01	77°43'	810.9
Mirzapur	25°09'	82°35'	1043.4
Moradabad	28°52'	78°47'	982.4

contd......

Table VII (Contd........)

1	2	3	4
Muzaffarnagar	$29^o28'$	$77^o41'$	838.0
Naini Tal	$29^o17'$	$79^o21'$	1722.6
Pilibhit	$28^o28'$	$79^o48'$	1275.6
Pratapgarh	$25^o54'$	$81^o57'$	996.9
Rae Bareli	$26^o14'$	$81^o14'$	918.5
Saharanpur	$29^o57'$	$77^o33'$	936.1
Shahjahanpur	$27^o53'$	$79^o55'$	1056.3
Sitapur	$27^o34'$	$80^o41'$	966.6
Sultanpur	$26^o16'$	$82^o05'$	999.1
Unnao	$26^o32'$	$80^o30'$	805.8
Varanasi	$25^o20'$	$83^o00'$	1075.9

1) The area of the lowest rainfall is situated in the western part of Uttar Pradesh comprising the districts of Mainpuri, Mathura, Agra, Aligarh and Etah.

2) The areas of heavy rainfall are: i) the hilly regions receiving rainfall above 200 cm, ii) the north-eastern region with rainfall above 110 cm and iii) the southern border of the state with rainfall exceeding 100 cm.

1 Pathak, B.D., Hydrogeology and Groundwater Potential of Uttar Pradesh, Lucknow, 1978, pp.2-8.

3) The high gradient of rainfall variation is found to occur in western Uttar Pradesh, and the lowest gradient lies in a belt around Bahraich, Gonda and Gorakhpur. An area of low gradient is spread around in a line joining Agra, Mainpuri, Kanpur, Fatehpur and Varanasi.

4) The low 'baggy' areas of Uttar Pradesh, Jhansi and Mirzapur districts, receive 90 and 102 cm respectively.

The rainy season occasionally assumes sultry condition which is more confined to the northern and eastern sections. There is dominance of Bay currents. Occasionally the dying Bay depressions are revitalised by the Arabian Sea currents in the western part of the region.

The rainy season comes to an end by October with a sudden fall in temperature and amount of rainfall. Rainfall lowest not exceed 10 cm in October throughout the region. The months of October and November which are transitional months are characterised by the second minima of relative humidity, unstable atmospheric conditions and often fair weather. The months of December and January are marked by further fall in temperature and prevalence of dry and chilly westerlies occasioned by the western depressions associated with welcome rain and cold waves. 5 per cent of the total annual rainfall is received from the winter monsoon. This amount of rainfall, associated with the dampness of atmosphere (R.H.55% - 75%) and lower potential erapotranspiration due to the low temperature, becomes more effective and beneficial to the 'rabi' crops.

Soil

Soil formation is a very slow but ceaseless process. The climate, particularly the rainfall acting over a long period of time, is the most important factor responsible for successive changes in soil development. In this region of almost uniform lithology, the soils are by and large, homogeneous. The alluvial soils with the variants the 'usar' and 'bhur', depending on the drainage conditions, mechanical and chemical constituents and the climatic characteristics are observed in different parts. Soils of Uttar Pradesh may broadly be divided into four classes.

1) The alluvium of the west and the north-west -- lighter in texture.
2) The alluvium of the east -- Heavier in texture.
3) The alluvium of the centre -- Texture intermediate between the east and the west.
4) The alluvium of the north-east -- Developed on calcareous parent material.

Soils tend to become heavier from the north-west to the south-east. Patches of alkaline soil and alluvium covered by sand are found in Agra, Aligarh, Mathura and Meerut districts. Therefore some water samples which had been collected by 'Central Groundwater Board' from these districts are mildly alkaline and soft to slightly hard in nature.

In eastern Uttar Pradesh freshly deposited silt is found in relatively low lying areas. In the high lying parts, the soil consists of old alluvium, made up of yellowish clay with frequent deposits of kankar is found.

The foundation of the soils of Uttar Pradesh may be classified into three geological groups:

A) <u>The ancient crystalline and vindhyan rocks of the Southern plateau</u>

The Archaean terrain of Bundelkhand is covered by red soil. The soils grade from the poor, thin, gravelly light-coloured varieties of the uplands to the much more fertile, deep dark varieties of the plains and valleys. They are deficient in phosphorus, nitrogen and humus. The alkali content is fair.

B) The Tertiary and Mesozoic Sedimentary Rocks of the Himalayas

Soil of this group covers only a small area of the hilly and mountainous ground of the Himalayas. They do not constitute a compact soil group.

C) The Recent and Sub-recent Rocks of the Indo-Ganga Alluvium

This soil is found in major part of the state. The prominant features of the soils are derived from their deposition as silts by the tributaries of Ganga. Geologically this alluvium is divided into khadar and bhangar.

The khadar soils, relatively rich in plant nutrients, occupy the narrow frequent siltation tracts in the flood plains of the rivers. Neutral to alkaline in reaction, these are deficient in organic material particularly phosphorus, and are sandy to loamy in texture. The Ganga khadar soils have immature profiles with sandy to silty loam texture, lack of concretion, fair proportion of lime and other soluble salts and are alkaline in reaction with imperfect drainage. Contrary to this the Yamuna khadar soils have sub-mature profile with predominance of clay and concretion and very high lime and other soluble salt contents under the poor drainage condition.

The bhangar soils are more extensive in areal spread, occupying the interfluvial zones. In the proximity of the Ganga these are loamy to sandy loam in texture while near the Yamuna the silt content decreases giving sandy to sandy loam texture possibly due to the excessive drainage.

Usar soil, which is caused by the efflorescene of sodium carbonate and sulphate under the alternating rainy and dry season, higher water table and alkaline composition is found in Sultanpur, Pratapgarh, through Rae Bareli, Lucknow, Hardoi and Shahjahanpur districts. Canal irrigation is also aggravating the 'Kallar' problem. Locally the reaction varies depending on the sodium and calcium content as in the humid climatic conditions of Pratapgarh the predominance of sodium provides the usar soil a neutral to acidic character whereas in Lucknow tract additional materials, the calcium, makes it highly alkaline.

The 'bhur' the sandy river deposit is highly localised in Ramganga tract and in narrow belt along the Ganga.

AGRICULTURE AND IRRIGATION

The major portion of the land in the state of Uttar Pradesh is utilized for agricultural purposes. Land utilization figures from 1978 to 1984 are shown in Table VIII.

Table VIII

Land Utilization

('000 hectares)

Items	1978-79	1982-83	1983-84
Reporting Area	29,809	29,748	29,755
Forest	5,109	5,120	5,121
Barren and Unculturable Land	1,146	1,120	1,105
Land Put to Non-agricultural Uses	2,218	2,336	2,352
Culturable West	1,338	1,147	1,130
Permanent Pastures and other Grazing Land	298	299	298
Land Under Miscellaneous Tree Crops and Groves	679	568	548
Current Fallow	932	1,176	1,160
Other Fallow	607	756	780
Net Area Sown	17,482	17,226	17,262
Area under more than once	6,819	7,482	7,806

Source: Statistical Dairy, Uttar Pradesh, Lucknow, 1985, pp.122-124.

It is obvious from the above Table VIII that net sown area has decreased in 1982-83 and 1983-84. While area which was sown more than once has increased. Culturable waste barren and unculturable land, land under miscellaneous tree crops and groves have also decreased.

The principal crops sown in the state are wheat, paddy, barley, pulses, maize and mustard. The area sown under principal crops in Uttar Pradesh during 1978 to 1984 is as given in Table IX.

Table IX

Area under Principal Crops in U.P.

('000 hectares)

Crops	1978-79	1982-83	1983-84
1	2	3	4
Cereals	16,792	17,043	17,745
Paddy	5,147	5,064	5,352
Wheat	7,391	8,296	8,528
Barley	869	627	608
Juar	658	564	645
Bajara	930	954	1,040
Maize	1,177	1,048	1,116
Other Cereals	620	454	457
Pulses	3,103	2,979	2,832
Urd	174	188	223

contd........

Table IX (Contd.......)

1	2	3	4
Moong	103	166	151
Arhar	501	480	518
Gram	1,641	1,506	1,358
Other Pulses	684	639	582
Oilseeds (pure)	782	1,256+	1,086+
Ropeseed & mustard	306	825+	690+
Groundnut	324	299	233
Other Oilseeds	152	132	163
Sugarcane	1,634	1,783	1,688
Potato	277	271	299
Tobacco	9	11	14
Cotton	31	35	30
Jute	11	8	6

+ Toria is also included.
Source: Statistical Diary, Uttar Pradesh, Lucknow, 1985, pp.133-134.

It is obvious from this Table IX that there is an increase in the production of cereals particularly wheat, paddy, and bajra from 1979 and onwards. Contrary to this decreasing trend is existed in the production of pulses. Production of oilseeds and sugarcane was highest in 1982-83.

Details of the area irrigated by different sources in the state from 1978 to 1984 is as given in Table X.

Table X

Area Irrigated by Different Sources in U.P.

('000 hectares)

Item	1978-79	1982-83	1983-84
a) Net Irrigated Area			
Canal	3,117	3,327	5,338
Tubewells	4,207	5,379	5,468
Wells	1,015	692	615
Tanks, lakes and ponds	232	167	152
Other	321	319	316
Total	8,892	9,884	9,889
b) Gross Irrigated Area	10,575	12,125	12,148

Source: Statistical Diary, Uttar Pradesh, Lucknow, 1985, p.146.

Above Table X indicates that there is an increase in gross irrigated area. Area irrigated by canal and tube-wells is continuously increasing. Use of wells, lakes, tanks and ponds is decreasing day by day.

CHAPTER V

OCCURRENCE, QUALITY, DISTRIBUTION AND UTILISATION OF GROUNDWATER RESOURCES IN U.P.

From historic times development of groundwater has occupied an important place in Uttar Pradesh. Even from the pre-historical times, through the medieval period, right into the modern times, wells have been one of the important sources of water supplies. There are millions of wells dotted all over the state. The mid-forties saw the emergence of tubewells, but the real break through in the field of groundwater development came after the era of planned development. Groundwater hereafter was not merely the source of domestic water supply for the village but much more importantly also came to be recognised as a dependable source for irrigation. During the last decade, there has been a significant improvement in the development of groundwater resources.

The ever increasing reliance on groundwater to meet the growing requirements of water supply has considerably accelerated the construction programme of groundwater structures throughout the state. During the last few decades, geologist have been playing an important role in identifying the groundwater and advising farmers about the proper placement of wells and tube-wells. As years pass by, this has assumed greater significance and the success of a well or a tube-well will now depend upon the correct analysis of the aquifer in the region and the potential for exploitation.

Eastern Uttar Pradesh has made tremendous progress in irrigation development and agricultural production mainly because of the exploitation of groundwater. The drought of 1965-66, 1979 and 1987 highlighted the importance of groundwater exploitation. Agricultural growth with stability can be achieved only by developing speedily our groundwater resources. It is, therefore, essential that steps are taken to identify all our groundwater resources and scientific planning done for their systematic exploitation.

Groundwater development has not been uniform in all the regions. Complex hydrogeological framework makes development and management of groundwater resources a challenging task, particularly in areas having inherent problems of salinity hazards. All our efforts are under way to harness the available groundwater resources for productive use particularly in augmenting the irrigation potential to stabilise agriculture.

HYDROGEOLOGICAL SETTING

Diversified hydrogeological set up has given rise to widely varying groundwater conditions in the state. Groundwater is available almost everywhere, but the nature of its occurrence and size of the reservoir is dependent on the geological framework. All the groundwater cannot be recovered from water bearing formations in which it occurs. Some lies in rock formations so deep that economics of pumping alone rules out its recovery. Some lie in such aquifer horizons that resist recovery in varying degrees and even may defy the pumping efforts.

Diversified geological formations, lithological variations, tectonic complexity, geomorphological and hydrometeorological dissimilarities prevailing in the state give rise to a large variety of groundwater situations. Howevever, in relation to mode of occurrence of groundwater, hydraulic properties of water bearing formation and groundwater regime characteristics, the hydrogeological framework of the state can be divided into the following five hydrogeological zones (Fig.I)

The 'Bhabar' the 'Tarai' and major parts of the Central Ganga Alluvial Plains have extensive and highly productive aquifers. In general, the yield prospectus of the Marginal Alluvial Plain is relatively low, where the

Table XI

Hydrogeological Zone

Zone	Sub-Zone	Approximate area sq. km
1. Himalayan	i) Lesser and Central Himalayas	59,257
	ii) Sub-Himalayas or Siwalik	3,000
2. Intermontane Valley		1,020
3. Alluvial Tract	i) Bhabar	2,460
	ii) Tarai	11,200
	iii) Central Ganga Plain	176,000
	iv) Marginal Alluvial Plain	19,728
4. Vindhyan Terrain		10,468
5. Bundelkhand Granite Terrain		11,280

aquifers are commonly lenticular and of limited extent, although the northern part of the belt does contain extensive and potential aquifers. Hydrogeology of the above five zones have been discussed below.

1. HIMALAYAN ZONE

It covers an area of 62,257 sq. km. It can be sub-divided into two sub-zone namely: The lesser and central himalayas and the siwalik.

The main boundary fault demarcates the boundary of the two sub-zones.

The Himalayan zone forms the northern most part of the state. This zone covers the district of Uttar Kashi, Tehri and Pauri Garhwal, Chamoli, Pithoragarh, Almora and part of Naini Tal. The northern limit of this zone is the southern boundary of trans-Himalayas.

The Himalayan zone is underlain largely by sedimentary rocks of Palaeozoic to Cenozoic era. These rocks have been greatly deformed by tectonic movements and at places metamorphosed during the Orogeny of the Himalayas. The highland is dissected by deep gorges and narrow valleys some of which are partly filled with quaternary alluvium. The lithological units include sandstone, shales, clays and conglomerates of Siwaliks followed northwards by the peletic and calceous sediments and the crystallines of the Lesser and Central Himalayas. In this hilly area, ground-water occurs in localised, disconnected patches under favourable geological and structural conditions and emerges out as numerous perennial springs. At places river terraces also serve as favourable locales for groundwater repository. Groundwater potentiality of the Himalayan zone is not known.

2. INTERMONTANE VALLEYS

The Doon Valley is the best example of intermontane valley in the state of Uttar Pradesh. It is spindle shaped tectonic valley, bounded by lesser Himalayas in the north and the Siwalik Hills in the south. The valley is underlain by unconsolidated sediments, comprising of boulders, cobbles, pebbles, gravels and sands intercalated with clay, Groundwater in the valley occurs under water table, perched and confined conditions.

3. ALLUVIAL TRACT

This zone extends from the north-west to the south-east direction and covers an area of 209,388 sq. km. This lowland occupies a great crustal down-buckle of fore-deep formed between the mobile orogenic belt of the Himalayas and the Static Peninsular shield. The fore-deep is filled with late tertiary sediments and quaternary alluviam which at places attains a thickness of more than 1000 metres. This pile of unconsolidated sediments holds the most potential aquifers in the state. The alluvial tract is further divided into four sub-zones (from north to south), viz., Bhabar, Tarai, Central Ganga Plain and Marginal Alluvial Plains.

Details of these sub-zones will now be discussed in following paragraphs.

a) Bhabar

The northern boundary of the bhabar belt is marked by the southern edge of siwalik hill ranges and the southern limit is demarcated by a line of issuing springs which also demarcates the northern limits of tarai. The width of bhabar belt ranges between 10 to 30 km. This sub-zone is composed of piedmont deposits formed due to lateral coalescence of fan deposits of innumerable streams emerging out of the hills. Lithologically 'bhabar' belt is constituted mainly by unsorted mixture of sands, cobbles, pebbles and boulders with some clays.

This bhabar belt is highly porous and permeable. Most of the rivers and streams traversing this zone are known to lose considerable amount of their flows (sometimes entirely), and as such, form one of the most prominent geological formations with great groundwater recharge potentialities for the extensive aquifer system of this Ganga basin. Groundwater in this belt mostly occurs in an unconfined state and the water table is generally deep being 30 metres or more below land surface. Perched water bodies are of common occurrence.

Inspite of holding good groundwater potential, the northern fringe of this zone is difficult for groundwater development because of deep water table and difficulty in drilling due to the presence of large boulders. However, in the southern part, the water-table conditions are favourable and drilling is not very difficult. Along the northern margin of the bhabar towards the centre the water-table is commonly as much as 30 metres or more below the land surface but down this slope the depth to water progressively decreases to a live of springs when the water-table intersects the land surface.

b) Tarai

This belt possessing some distinctive hydro-geological characteristics occurs down slope of the bhabar belt. The spring line mentioned in the preceeding paragraph marks the northern limit of the tarai belt, which runs almost parallel to the bhabar belt. The general width of tarai belt ranges from 8 to 16 km. This tract begins from where river flows reappear at the surface and where again the groundwater table and the land surface, intersect. Under favourable conditions of topography this give rise to groundwater effluence at land surface leading often to marshy conditions. The tarai follows the bhabar down slope almost everywhere but does not have a uniform width.

Lithologically the tarai belt is constituted predominantly by clays with intercalations of sands and occasional pebbles and boulders. In the tarai belt, sediments begin to display better sorting, indicate semblance of stratification in as much as the sands and clays exhibit alternations. This aspect of deposition land importance to the tarai from groundwater point of view. The clay horizons, often quite significant and extensive in character have succeeded in confining the sand horizons (aquifers) rather effectively so much so that groundwater structures piercing such aquifers are known to flow naturally (artesian condition) at land surface. The tarai particularly in the districts of Naini Tal, Bareilly, and Pilibhit where it has attained optimum dimensions, is generally called the "Artesian Belt'. This is because most of tube-wells put down in the belt have resulted in prolific free-flowing wells often with hydro-static heads several metres above the land surface. There are several aquifer horizons with depth, most of which display artesian conditions and seem to possess varying yield characteristics and hydrostatic head, factors which merit due consideration while planning groundwater development programmes.

Groundwater in strata at depth of less than 50 metres in the tarai is generally unconfined and the water table is normally within four metres below land surface. However, groundwater in the deeper aquifers occurs under confined corditions, because of the overlying thick clay bed which provides the confinement. A characteristic feature of the tarai belt is the occurrence of frequent free flowing groundwater condition with the piezometric head remains above ground level in such instances. The recharge of groundwater in the confined aquifers most probably, takes place by downward percolation and lateral flow from the bhabar belt.

c) <u>Central Ganga Alluvial Plain</u>

Down slope of tarai, over a greater part of the Ganga basin occurs a most extensive and widely distributed tract often called the Central Ganga Tract. The northern limit of this zone matches with the southern peripheral boundary of the tarai while the southern limit is formed by and large by the stretch of the Ganga down stream of its confluence with Yamuna. Stretching from west-north-west to east-south-east this sub-zone covers the major part of the state and contains several potential aquifers at varying depths. The Central Ganga Alluvial Plain is underlain by a series of fresh water aquifer horizons down to great depths. Quaternary alluvium in this sub-zone is made up chiefly of clay, silt, sand, gravel and kankar admixed in varying proportion. The beds are generally lenticular and there are rapid alternations and gradations between granular and clayey horizons. The sand and clay members exhibit wide variation both in their lateral and vertical extension, building up an interconnected and regionally extensive aquifers system.

The near surface groundwater is unconfined while deeper aquifers generally contain water under confined to semi-confined conditions. Central Ganga Alluvial Plains hold a great promise for groundwater development on a massive scale.

Groundwater exploration in the belt has largely been restricted to the central and eastern parts of the state in the districts of Azamgarh, Bahraich, Ballia, Basti, Faizabad, Ghazipur, Gonda, Jaunpur, Kanpur, Pratapgarh, Rae Bareli and Sultanpur. Exploration in the western part of the state is yet to be intensified. Results of exploratory drilling by the Central Ground Water Board in recent years have brought to light the basement configuration. Granite basement was encountered at 500 metres depth at Panki (Kanpur district), at 470 metres depth at Sultanpur Jarauli (Rae Bareli district), at 538 metre depth at Kurni (Jaunpur district). Vindhyan shale was met with at 379 metres depth at Aligarh, Vindhyan Sandstone at 450 metres depth at Jajmuiya (Kanpur district), Vindhyan limestone at 389 metres depth at Sakera (Jaunpur district), whereas no bed rock was touched even down to 700 metres depth at Lucknow and Banka (Ghazipur district).

The principal aquifers underlying the Central Plains attain considerable thickness; thickness of individual aquifers vary from 25 metres to as much as 330 metres. Depth to water level in tube-wells generally ranged between 2 and 12 metres below land surface.

d) Marginal Alluvial Plain

This sub-zone lies between Central Ganga Plain and the southern rocky terrain. Alluvium here with its limited thickness is composed of silt, clay, kankar and sands of various grades with occasional gravel. The granular horizons have limited vertical thickness and areal extent displaying, as it were, a discontinuous aquifer system. The fringe sediments in western Uttar Pradesh appear to have aquifer horizons often displaying salinity hazards. But in the rest of the area, particularly eastward, the sediments in the fringe zone exhibit increase in the granular materials and near elimination of the salinity hazard.

Groundwater in this belt occurs under unconfined to confined conditions. The tract holds promise for ground-water development on a moderate scale. Exploratory drilling by Central Ground Water Board was carried out down to a maximum depth of 280 metres at Susirkalan in Mathura district. A prominant and persistent granular zone comprising fine to coarse grained sand with varying amount of gravel has been encountered between the depth of 30 and 170 metres in the northern part of the sub-zone. The clay overburden apparently increases in thickness from Gaipur in Murzapur district towards west. The thickness of alluvium is not much in this belt and bedrock (Bundelkhand granite) has been encountered at several places in the district of Jalaun, Hamirpur and Banda between the depth of 60 and 150 metres. Vindhyan Limestone, shale and sandstone have been encountered in the district of Mathura, Allahabad and Mirzapur between the depths of 60 and 275 metres.

The static water level in tube-wells generally range from flowing conditions to 26 metres below ground level.

4. VINDHYAN TERRAIN

This tract which differs considerably from the main part of the state lies in the southern part of Uttar Pradesh. This region is underlain by the rocks of Vindhyan system. Vindhyan terrain covers the districts of Mirzapur, Allahabad, Banda, Hamirpur and Jhansi. Lithologically this region is mainly constituted by fine to coarse and gritty sandstones, quartzites, limestones, shales and phylites. The rocks of Vindhyan terrain are consolidated sandy, cemented and impervious. Primary openings in these rocks do not exist. The shales are relatively more impervious. Groundwater movement through these rocks is apparently concentrated along bedding planes and joints or other secondary fractures. Hitherto the quartzites and sandstones were believed to be poor aquifers because of their compact nature. Artisian flowing conditions exists in the rocks of Upper Vindhya system. Generally, the area is dry and problematic from the point of view of groundwater development.

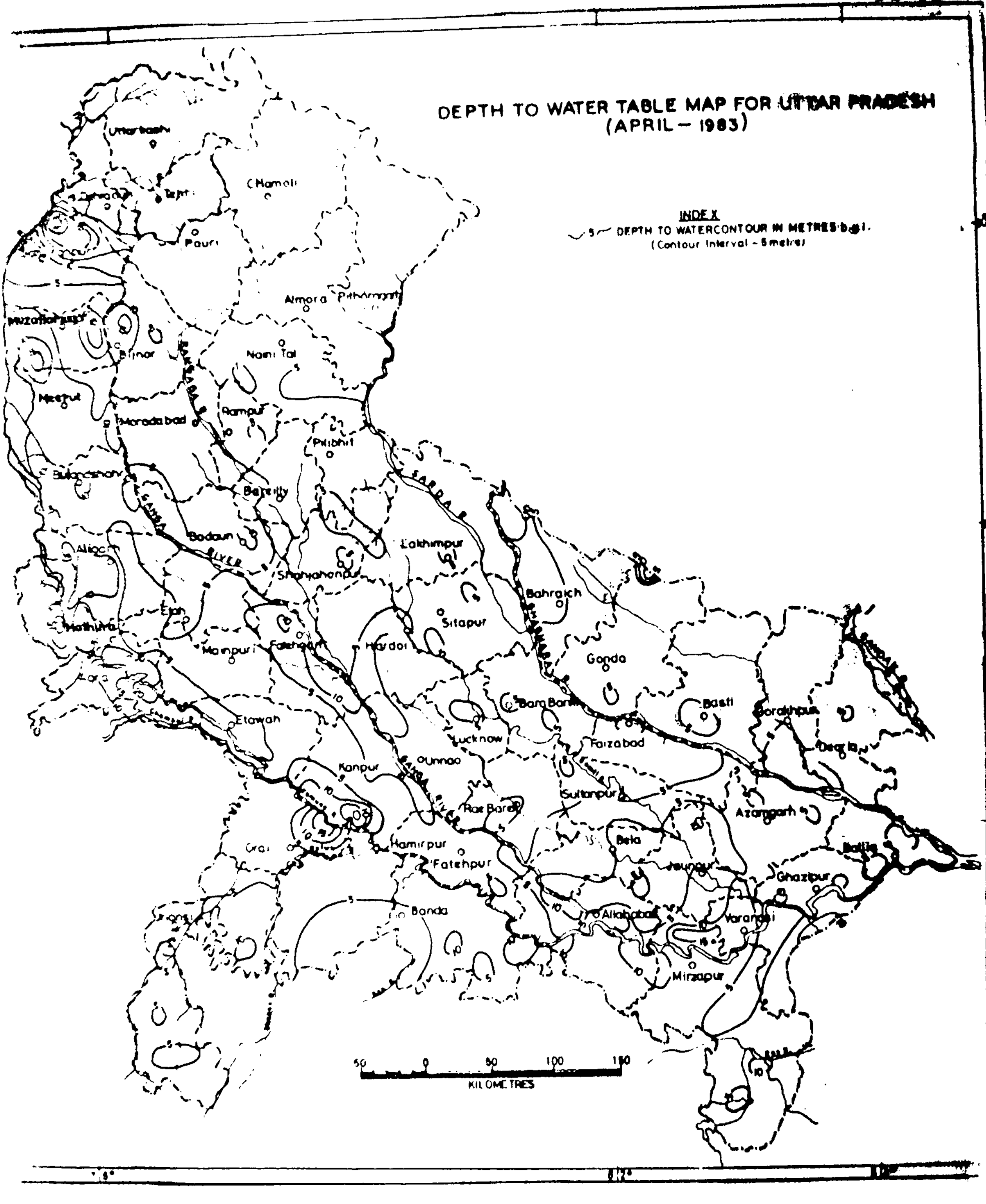
DEPTH TO WATER TABLE MAP FOR UTTAR PRADESH
(APRIL – 1983)
INDEX
5 DEPTH TO WATERCONTOUR IN METRES b.g.l.
(Contour Interval - 5 metre)
Chamoli
Pauri
Almora
Naini Tal
Bijnor
Meerut
Moradabad
Rampur
Pilibhit
Bulandshahr
Bareilly
Badaun
Aligarh
Lakhimpur
Shahjahanpur
Bahraich
Sitapur
Etah
Mathura
Mainpuri
Hardoi
Gonda
Basti
Gorakhpur
Deoria
Etawah
Lucknow
Faizabad
Kanpur
Unnao
Sultanpur
Azamgarh
Rae Bareli
Hamirpur
Fatehpur
Bela
Jaunpur
Ghazipur
Ballia
Banda
Allahabad
Varanasi
Mirzapur
SARDA R.
50 0 50 100 150
KILOMETRES

Fig.1

5. BUNDELKHAND GRANITE TERRAIN

The Bundelkhand Gneissic Complex includes granite and genisses of Archean age. The Bundelkhand granite massif is composed in parts of the districts of Jhansi, Banda, Hamirpur and Mirzapur. Groundwater occurs in the weathered zone in fractures, joints and fissures under water table conditions. This zone is not promising for groundwater development.

DEPTH TO WATER TABLE

The State of Uttar Pradesh can broadly be divided into six zone from point of view of depth. These six zones are: Bhabar, Tarai, Central Ganga Alluvial Plain, Ganga-Yamuna Interstream area, Marginal alluvial plain and southern rocky terrain. Depth to groundwater maps for June, April and November indicates the exact position.

1. Bhabar

In this belt water table is generally deep. In Saharanpur district situated in northwestern part of the state depth to water table is 36 metres.

2. Tarai

The tarai belt extends from Saharanpur in north-west to Gorakhpur in north-east. This region is characterised by

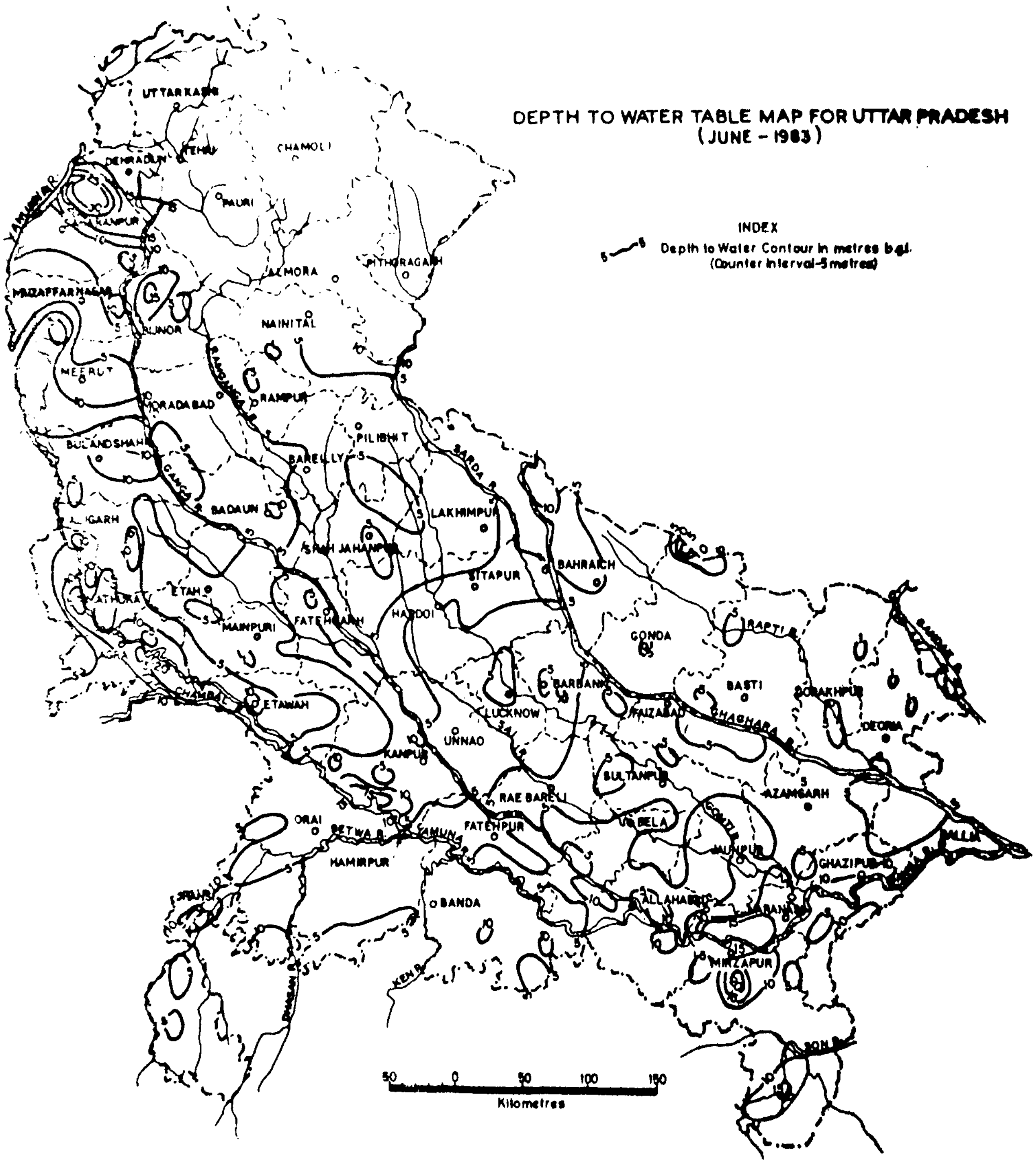
DEPTH TO WATER TABLE MAP FOR UTTAR PRADESH
(JUNE - 1983)
INDEX
Depth to Water Contour in metres bgl.
(Counter Interval-5 metres)
Kilometres

Fig.2

shallow water table particularly during and after monsoons periods. Generally the depth to water table is 5 metre. Due to shallow water table swampy conditions occur in this region.

3. Central Ganga Plain

Immediately south of the tarai belt is located the wast Central Ganga plain. In this region the water level generally rests between 5 and 10 metres. In the central command area water level is lower than 2 metres due to seepage from artificial surface bodies.

4. Ganga-Yamuna Interstream Area

In this region water table conditions are different from the Central Ganga Plain. Water level is deeper than 14 metres in this area.

5. Marginal Alluvial Plain

The southern part of the state is covered by the Marginal Alluvial Plain. In this area the water level generally rests between 5 and 15 metres below ground level.

6. Southern Rocky Terrain

This region forms the southern most sub-zone of the state. In this area water table are not very deep,

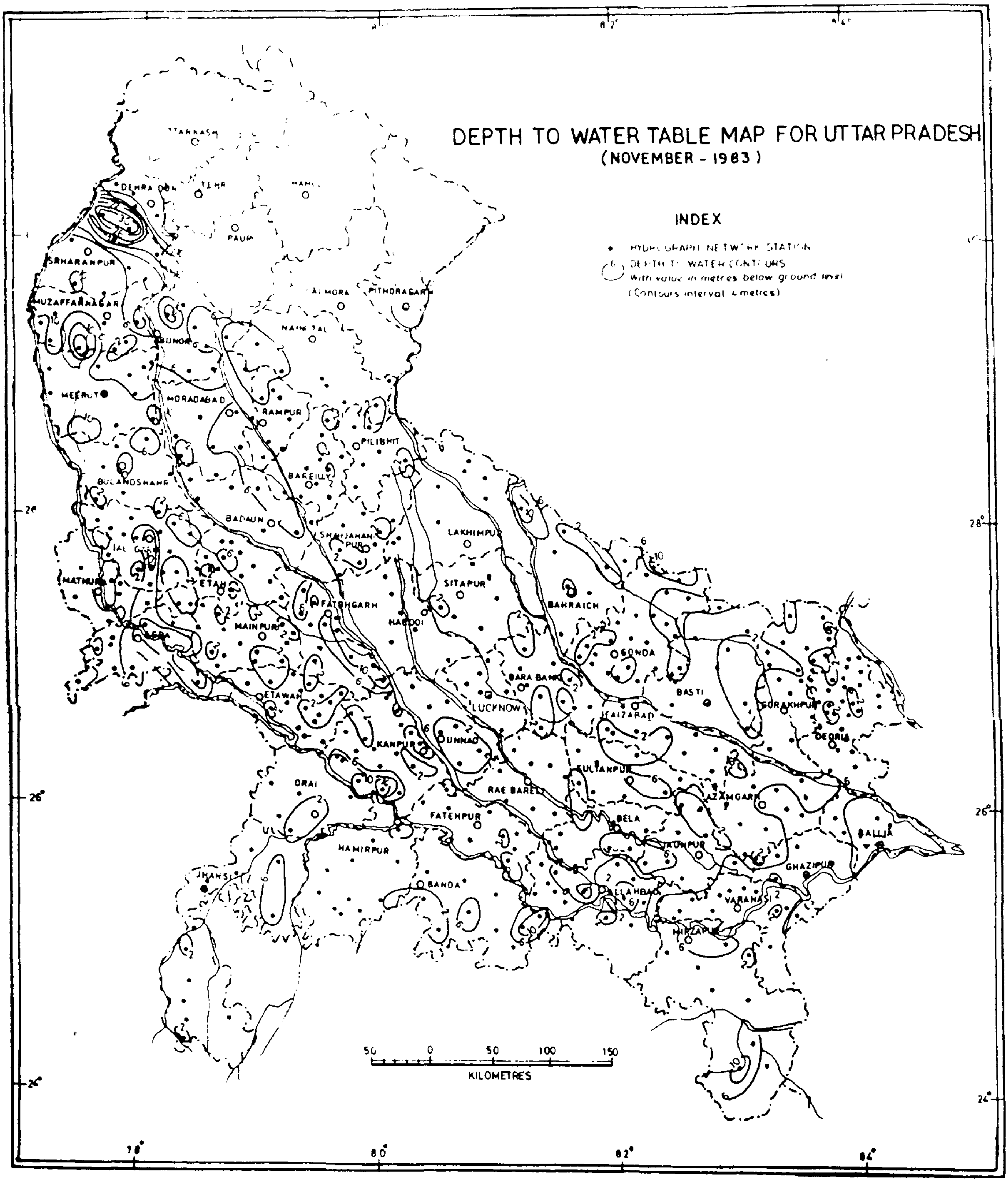
DEPTH TO WATER TABLE MAP FOR UTTAR PRADESH
(NOVEMBER - 1983)
INDEX
With value in metres below ground level
(Contours interval 4 metres)
50
0
50
100
150
KILOMETRES
DEHRA DUN
SAHARANPUR
MUZAFFARNAGAR
BIJNOR
MEERUT
MORADABAD
RAMPUR
PILIBHIT
BAREILLY
BULANDSHAHR
BADAUN
SHAHJAHANPUR
LAKHIMPUR
MATHURA
ETAH
SITAPUR
FATEHGARH
BAHRAICH
MAINPURI
HARDOI
GONDA
BARA BANKI
ETAWAH
BASTI
LUCKNOW
GORAKHPUR
FAIZABAD
DEORIA
KANPUR
UNNAO
SULTANPUR
ORAI
RAE BARELI
AZAMGARH
FATEHPUR
BELA
JAUNPUR
BALLIA
HAMIRPUR
GHAZIPUR
JHANSI
BANDA
VARANASI
MIRZAPUR
ALMORA
PITHORAGARH
NAINI TAL
PAURI
28°
26°
24°
78°
80°
82°
84°

Fig.3

generally lying within 5 metres of the land surface. However at some places the water table may be more than 10 metres deep.

SEASONAL FLUCTUATION

Water table fluctuation map has been prepared on the basis of water level of June 1983 and November 1983. The maps indicate a rising trend in water level almost throughout the state between June and November 1983. Generally the rise in water level varies from 2 metres to 6 metres. In some parts of the Southern Rocky Terrain and the Marginal Alluvial Plain the rise in water level ranges between 10 to 16 metres. On the other hand Gorakhpur and Ballia districts show a decline in water level ranging from 2 to 4 metres during the post-monsoon period. Increased groundwater draft is responsible for this critical condition.

QUALITY OF GROUNDWATER

The quality of groundwater is as important as its quantity. Information regarding the quality of groundwater is limited. But development and utilisation of groundwater resources could be planned systematically and scientifically only when the chemical character of groundwater is fully known. For example, water can be safe for drinking purposes

MAGNITUDE OF WATER TABLE IN UTTAR PRADESH FLUCTUATION BETWEEN JUNE & NOVEMBER 1983

INDEX

• Hydograph network Station

Decline in water level

Rise in water level

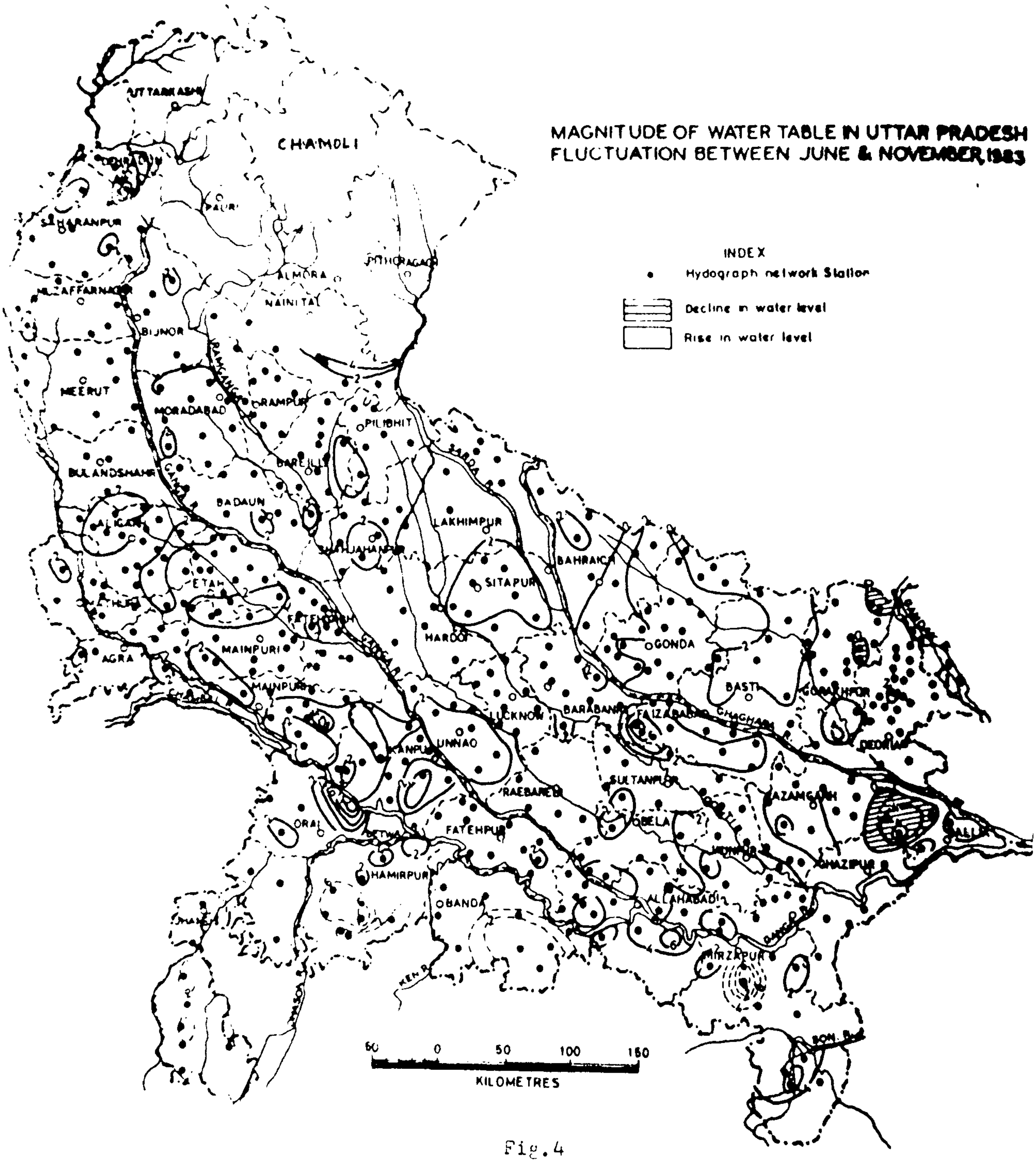

Fig.4

if it is generally free of contaminants, it can be put to use for agricultural production provided the chemical quality of groundwater is conducive to crop growth; it can be utilised in a particular industry if the quality is, such as not to create adverse reactions.

Groundwater moves slowly through rock media. In the process it gets the necessary environment for prolonged contact with minerals that constitute the rocks. As a result there is a physiochemical interaction of rocks and groundwater. Most of the minerals are soluble, with varying degrees of solubility. Mineral content, therefore increases in groundwater as it moves along until a balance or equilibrium of the dissolved substances is attained.

There is a large variety of geological formations with equally large number of rock units. Some are of igneous origin, some sedimentary and some metamorphic. These have given rise to a variety of rock formations having different chemical composition. Groundwater circulating in these rock formations develops a chemical character conformable to the constituent minerals comprising the rock formations. Indeed, there are many variables in the environment that effect the chemical process. The quality of groundwater is therefore governed by, soil characteristics and by the nature of strata through which it passes. Consequently ample variation is found in the quality of groundwater at different places. General conclusions drawns about groundwater resources of Uttar Pradesh from the reports of Central Groundwater Board are given below.

<u>Hydrogenetion Concentration</u>

Water from shallow aquifers are mildly alkaline and soft to slightly hard in nature. Values of pH generally ranges between 7.5 to 8.5. Mostly the pH of water is within the permissible limits for potabic water. In general, water is suitable for domestic and irrigational purposes. However, in few districts such as Fatehpur and Jhansi (partly) brackish and saline groundwater has also been found respectively.

<u>Specific Conductivity</u>

A comprehensive study of the data which was collected by Central Ground Water Board indicates that the specific conductivity of shallow groundwater generally ranges between 293 to 2071 micromhos/cm 25°C.[1] Higher values are noticed

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1 Pathak, B.D., <u>Hydrogeology and Groundwater Potential of Uttar Pradesh</u>, Lucknow, 1978, pp.113-143.

in south-western districts such as Agra, Aligarh, Mainpuri, Mathura and Etah. Higher mineralisation of groundwater occurs in southern and eastern districts of the such as Jhansi, Fatehpur, and Ballia. Highest specific conductivity has been recorded at Fatehabad in Agra district which is 6630/micromhes/cm at 25°C.

Total Hardness

Total hardness ($CaCo_3$) of groundwater in major part of the state varies between 221 and 1500 parts per million. Most of the water in the state is found within the permissible limits. In the districts of Agra, Azamgarh, Ballia, Badaun, Etah, Fatehpur, Hamirpur and Jhansi concentrations have exceeded 3000 parts per million. Highest concentration of 380-6666 ppm is found in Fatehpur district.[1]

Bicarbonate

Bicarbonate concentration (HCO_3) ranges between 46 and 1405 parts per million. Lowest and highest concentration of bicarbonate has been recorded in Gonda and Agra districts respectively. HCO_3 content in groundwater

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1 Handbook of Districtwise Hydrogeological Informations, Uttar Pradesh, Lucknow, 1984, p.25.

is dependent upon the partial pressure of carbon dioxide in the soil. HCO_3 shows wide fluctuations depending upon CO_2 pressure in the soil, quite independent of the aquifer characters.

Fluorides

Fluoride is an essential element for the growth of tooth, while higher concentration of fluoride causes tooth decay. Further high concentration may prove fatal. The desirable limit of fluoride in drinking water is 1.00 ppm and the excessive limit is 2.00 ppm. In major part of the state fluoride concentration is less than 1 mg/l. In some districts such as Agra, Aligarh, Barabanki, Basti, Fatehgarh, Rai-Bareli and Sultanpur fluoride concentration of 1.5 mg/l or 2 or more than 2 mg/l have been recorded.[1] The overall picture of fluoride concentration in shallow groundwater in Uttar Pradesh is not bad.

Calcium

Calcium is the most common element present in natural water. A human body requires 0.7 to 2.0 g. per day.

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1 Hydrogeological and Hydrochemical Data of National Hydrograph Network Stations in Uttar Pradesh for the Year 1983, Lucknow, 1985, p.12.

Absence of calcium is responsible for rickets, decayed teeth etc., while high concentration of calcium causes urinary disorder. In major part of the state, the concentration of calcium is 100 mg/l. In some water samples from Agra, Aligarh, Azamgarh, Ballia, Badaun, Basti, Moradabad and Jaunpur higher values of the order of 200 or 300 mg/l of calcium have been recorded. The highest value of 310 mg/l is recorded in Fathehpur district.[1]

<u>Chloride</u>

According to I.C.M.R. minimum and maximum permissible limits of chloride in potable water is 200 mg/l and 1000 mg/l respectively. Shallow groundwater of the state has chloride concentration within the desirable limits. In major part of the state the chloride concentration in shallow water is below 200 mg/l. However, a few higher values of the order of 500 mg/l or 1000 mg/l have also been recorded in water samples from Agra, Aligarh, Mathura, Badaun, Etah, Mainpuri, Jalaun, Hamirpur, Pilibhit, Sitapur and Barabanki districts.[2]

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1 ibid., 1985, p.12.

2 ibid., 1985, p.13.

Nitrate

Permissible limit of nitrate in potable water is 45 mg/l and its maximum permissible limit is 100 mg/l.

In major parts of the state the concentration of nitrate in shallow groundwater is within permissible limits. In some water samples from Agra, Banda, Fatehpur, Hamirpur, Jalaun, Jaunpur, Jhansi, Mainpuri, Mathura, Varanasi, Faizabad, Gonda and Naini Tal higher values of the order of 200 or more than 200 mg/l of nitrate have been recorded.

Sodium

Primary source of sodium in groundwater is from the release of soluble products during the weathring of plagioclase feldspar. In the state of Uttar Pradesh the concentration of sodium ranges between 4 ppm and 970 ppm. The concentration of 200 ppm of sodium in shallow groundwater may be injurious. Major portion of groundwater is within the permissible limits. However, in Agra, Aligarh, Etawah, Fatehpur, Etah, Mainpuri, Mathura, Hamirpur, Rae Bareilly and Sultanpur districts sodium concentration varies from 76 ppm to 970 ppm.[1]

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1 Pathak, B.D., op. cit., 1978, p.61.

Potassium

Common sources of potassium are the products formed by the weathering of orthoclase, microline, biotite, leucite, and nepheline in igneous and metamorphic rocks. The concentration of potassium in groundwater varies between 2 ppm and 1120 ppm. Concentration of potassium in groundwater is within permissible limits. In some water samples from Aligarh, Badaun, Bahraich, Bareilly, Etah, and Fatehgarh higher values of the order of 220 ppm have been found.[1]

Magnessium

It is responsible for the hardness of water. The concentration of magnessium varies in the groundwater of Uttar Pradesh from 4 ppm to 349 ppm. In major part of the state the concentration of magnessium is within the permissible limits of 50 ppm. However, in the districts of Ballia, Gonda, and in some parts of western Uttar Pradesh magnessium concentration is considering high.

For detailed chemical analysis of groundwater in Uttar Pradesh the entire state can be divided into six sub-basin. These sub-basins are Ganga, Yamuna, Ramganga,

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1 Pathak, B.D., op. cit., 1978, p.62.

Gomti, Ghagra and Betwa. Sub-basinwise percentage distribution of water is plotted on the map. Chemical characteristics of these basins will now be discussed here.

1) <u>Ganga Sub-basin</u>

In the Ganga sub-basin majority of groundwater samples belong to C_2S_1 and C_3S_1 class. Water belong to this class is suitable for irrigation.

Aligarh, Etah, Mainpuri and Allahabad districts belong to the class of C_2S_2, C_4S_2 or C_3S_2. This type of water may be used in irrigation with special soil water management practices. In the absence of proper drainage facilities it may cause hazards in long term perspective.

2) <u>Yamuna Sub-basin</u>

The quality of groundwater in Yamuna sub-basin is similar that of Ganga sub-basin. More than 70 per cent of groundwater belongs to C_1S_1, C_2S_1, and C_3S_1 class. Water samples belong to C_1S_1 class collected from Dehra Dun and Muzaffarnagar. 30 per cent water belong to C_3S_2, C_4S_2, C_3S_4 or C_4S_3 classes. Fatehpur is the only district which belongs to the category of C_4S_3. C_5 type of water is found in Aligarh, Agra and Fatehpur.

SUB-BASIN-WISE PERCENTAGE DISTRIBUTION OF GROUND WATERS IN UTTAR PRADESH ON U.S.S.L DIAGRAM

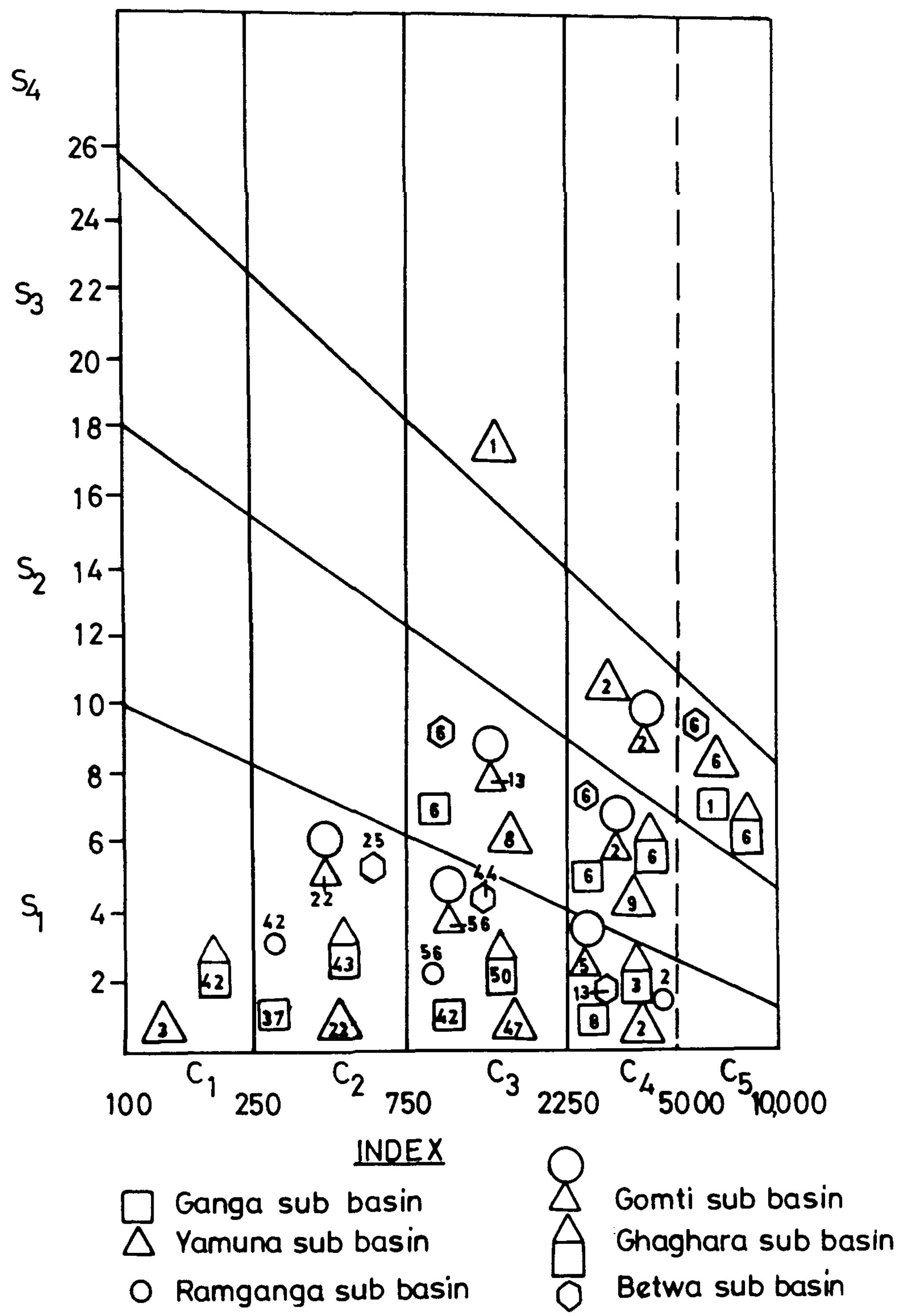

Fig.5

3) Ghagra Sub-basin

In this basin more than 70 per cent of groundwater belong to C_2S_1 and C_3S_1 classes and remaining water belong to C_1S_1 and C_4S_1 class. Basti and Gorakhpur districts fall in the category of C_4S_1.

4) Gomti Sub-basin

In this region majority of groundwater samples belong to C_2S_1 and C_3S_1 class and remaining water is widely scattered in C_4S_1, C_3S_2, C_4S_2 or C_4S_3 classes.

5) Betwa Sub-basin

This sub-basin has very small areal extent. In this region groundwater is widely scattered in C_2S_1, C_3S_1, C_4S_1, C_3S_2, C_4S_2 and C_5 classes.

6) Ramganga Sub-basin

More than 95 per cent of groundwater belong to C_2S_1 and C_3S_1 classes. Class which is unlikely to create any problem in irrigating the normal soils to grow semitolerant to tolerant crops under normal conditions.

DISTRIBUTION OF GROUNDWATER

Groundwater is a renewable resource, subjected to periodic replenishment primarily from precipitation. To have a measure of the quantum of such periodic increment to any groundwater body it is necessary to obtain information on the hydrogeological framework of the reservoir, the groundwater regime conditions and the factors governing the recharge and discharge from the groundwater system. Along with these, knowledge of the chemical quality of groundwater is basic for proper evaluation of the resource suitable for development.

The Central Groundwater Board has conducted detailed inter-disciplinary and integrated studies on a large scale for determining the water balance situation. For carrying out groundwater development programmes in an effective manner it is desirable to have an idea of available groundwater resource in various parts of the state. Districtwise groundwater resources are given in following table

On the basis of Table XII we can say that the percentage of net recoverable recharge is higher in the districts of Saharanpur, Muzaffarnagar, Etah, Hamirpur, Gorakhpur, Basti, Kheri, Gonda, Bahraich and Barabanki.

Table XII

Districtwise Groundwater Resources in U.P.

31.12.83) (M.C.M.)

District	Net Recoverable Recharge	Net Draft	Percentage of Groundwater Utilisation
1	2	3	4
Saharanpur	2538	705	28
Muzaffarnagar	2067	633	31
Meerut	1695	617	36
Ghaziabad	1191	529	44
Bulandshahr	1796	598	33
Aligarh	1720	752	44
Mathura	952	365	38
Agra	1042	559	54
Mainpuri	1277	534	42
Etah	2310	618	27
Bijnor	1265	560	44
Moradabad	1328	781	59
Rampur	907	334	37
Bareilly	1248	399	32
Budaun	952	652	68
Shahjahanpur	1180	487	41
Pilibhit	991	295	30

Contd.......

Table XII (Contd......)

1	2	3	4
Farrukhabad	277	584	21
Etawah	1248	376	29
Kanpur (Urban))) Kanpur (Rural))	1535	458	30
Fatehpur	1259	338	27
Allahabad	1523	550	36
Jhansi	778	272	35
Lalitpur	786	234	30
Jalaun	1435	114	8
Hamirpur	2388	171	7
Banda	1206	211	17
Varanasi	1283	505	39
Mirzapur	1498	237	16
Jaunpur	1532	676	44
Ghazipur	1086	473	44
Ballia	877	360	41
Gorakhpur	1977	668	34
Deoria	1950	498	26
Basti	2526	709	28
Azamgarh	1710	791	46
Nainital	692	218	32
Almora	-	-	-
Pithoragarh	-	-	-

Contd......

Table XII (Contd.......)

1	2	3	4
Tehri Garhwal	-	-	-
Uttar Kashi	-	-	-
Chamoli	-	-	-
Garhwal	-	-	-
Dehra Dun	554	17	3
Lucknow	743	400	54
Unnao	1354	300	22
Rae Bareli	1802	396	22
Sitapur	3046	682	22
Hardoi	1894	652	47
Kheri	3025	557	18
Faizabad	1626	691	43
Gonda	2819	656	23
Bahraich	2303	352	15
Sultanpur	1454	460	32
Pratapgarh	1032	362	35
Bara Banki	2153	376	17
Uttar Pradesh	77833	23755	31

Source: Statistical Diary, Uttar Pradesh, 1985, pp.151-154.

The districts of Mathura, Rampur, Budaun, Pilibhit, Farrukhabad, Jhansi, Ballia, Naini Tal and Dehra Dun have a very low percentage of net recoverable rechange of groundwater. The districts of Saharanpur, Aligarh, Moradabad, Gorakhpur and Azamgarh have a high percentage of net draft in comparison to other districts.

For hilly areas which covers the districts of Almora, Pithoragarh, Tehri Garhwal, Uttar Kashi, Chamoli and Garhwal data relating net recoverable recharge and net draft are not available.

On the basis of above discussion we can say that groundwater is not evenly distributed in the state. Distribution of groundwater is characterised by dissimilarity. Diversified geological formations, lithological variations, tectonic complexity, geomorphological and hydrometeorological dissimilarities prevailing in the state give rise to a large variety of groundwater situations.

UTILISATION OF GROUNDWATER

Groundwater is an important source of water supply. Its utilisation as a source of water supply has been known from time immemorial. Water from aquifer is put to various uses - agricultural use, domestic use for cooking, bathing washing, use in manufacturing and industrial concerns etc.

The rate of consumption continues to increase in irrigation, domestic use and industries. The principal utilisation of groundwater is through private minor irrigation works and state tubewells. The use for domestic, industrial and other purposes is insignificant as compared to agricultural use. Earlier it used to cater to the domestic requirements and only partially for irrigation purposes. In recent times, the pattern of groundwater utilisation has changed considerably. Today it is said that over ninety per cent of groundwater resources are used in the irrigation sector. As a result, the present practice of expressing the groundwater potential is only in terms of irrigation potential. Based on the statistical data available on the number of dugwells, dugwells fitted with persian wheels, pump sets and private tube-wells districtwise annual draft has been recorded. Estimate of net draft in the state of Uttar Pradesh in 1983 was estimated to be 23755 M.C.M. while net recoverable recharge of 77833 M.C.M. had been recorded in the same year.[1]

The net draft of groundwater is highest in the northern part of western Uttar Pradesh. Percentage of groundwater utilisation is also considerably high in western Uttar Pradesh. In some parts of eastern Uttar Pradesh

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1 Statistical Diary, Uttar Pradesh, 1985, p.154.

covering the districts of Jaunpur, Ghazipur, Gorakhpur, Azamgarh and Varanasi percentage of groundwater utilisation ranges between 39 to 46 per cent. Maximum utilisation of groundwater (68 per cent) had been recorded in Budaun in 1983.[1]

Irrigation used the largest amount of groundwater. Area irrigated by government and private tube-wells was 6224,00 and 4840400 hectare respectively.[2] The progressive increase of groundwater irrigation potential in the state can be had from the table below.

Table XIII

Irrigation Potential and its Utilisation in U.P.

(Thousand hectare)

Year/Items	Minor Irrigation		Major and Medium Irrigation	Total
	State	Private		
1981-82				
Potential	2,392	7,543	6,560	16,495
Utilisation	1,300	7,543	5,149	13,992
1982-83				
Potential	2,529	8,091	6,723	17,343
Utilisation	1,300	8,091	5,234	14,625
1983-84				
Potential	2,671	9,331	6,778	18,780
Utilisation	1,300	8,612	5,396	15,308
1984-85				
Potential	2,805	10,079	6,809	19,693
Utilisation	1,300	9,148	5,517	15,965

1 ibid., p.152.
2 ibid., p.145.
3 ibid., pp.149-150.

The table indicates that from 1981-82 onwards, groundwater irrigation potential and its utilisation has progressively increased. Groundwater utilisation however has not been uniform in all the districts. In districts like Moradabad, Aligarh, Agra, Budaun, Shahjahanpur, Varanasi, Jaunpur, Gorakhpur, Azamgarh, Faizabad and Lucknow, groundwater exploitation has exceeded the 50 per cent mark. In the districts of Jalaun, Hamirpur, Banda, Dehra Dun, Bahraich, Kheri and Barabanki groundwater exploitation is generally below 20 per cent.

There is a large scope for development of groundwater in Uttar Pradesh. At present only Moradabad and Budaun have developed their groundwater potential and others have groundwater potential to develop.

BIBLIOGRAPHY

Awasthi, S.C., Quality of Water in Relation to its Use, Indian Minerals, Vol.28, No.3, Calcutta, 1974.

Baldwin, H.L. and McGuinness, C.L., A Primer on Ground Water, 1970.

Braley, E. (ed.), The Earth's Physical Resources, Block 5, Water Resources, U.K., 1978.

Briggs, G.F. and Fiedler, A.G. (ed.), Ground Water and Wells, Minnesota, 1966.

Burrard, S.G., On the Origin of the Himalayan Mountains, Geological Survey of India, Professional Paper No.12, Calcutta, 1912.

Charlu, T.G.K. and Dutt, D.R., Groundwater Development in India, New Delhi, 1982.

Chatterji, G.C., Groundwater Studies in India: Pointers and Prospects, Indian Journal of Power and River Valley Development, Vol.XVII, No.12, Calcutta 1967.

Chorley, R.J. (ed.), Water, Earth and Man, London, 1969.

Clawson, M. (ed.), Natural Resources and International Development, Baltimore, 1964.

Dasmann, R.F., Environmental Conservation, London, 1968.

Fude, I., Conservation of Resources, Indian Journal of Power and River Valley Development, Vol.XXXV, No.9, Calcutta, 1985.

Fude, I., Problems in Water Resource Utilization, Indian Journal of Power and River Valley Development, Vol.XXXIII, No.6, Calcutta, 1983.

Griffin, F.Paul, et. al., Culture, Resource and Economic Activity: An Introduction to Economic Geography, London, 1976.

Guha, J.L. and Chattoraj, P.R., A New Approach to Economic Geography: A Study of Resources, Calcutta, 1964.

Hooder, B.W. and Rodger Lee, Economic Geography, New York, 1974.

James, Geikie, Earth Sculpture, London, 1898.

Krishnan, M.S., Geology of India and Burma, Madras, 1956.

Maitra, B., Water Resource Management - Its Needs and Means, Indian Journal of Power and River Valley Development, Vol.XXXIV, No.1, Calcutta, 1984.

Mitchell, B., Geography and Resource Analysis, London, 1979.

Murthy, Y.K., System Approach to Water Resource Planning, Indian Journal of Power and River Valley Development, Vol.XXV, No.9, Calcutta, 1975.

Oldham, R.D., The Structure of Himalayas and of the Gangetic Plain, Memoirs of the Geological Survey of India, Vol.XLII, Pt.II, Calcutta, 1917.

Pathak, B.D., Hydrogeology and Groundwater Potential of Uttar Pradesh, Lucknow, 1978.

Pereria, H.C., Land Use and Water Resources, London, 1973.

Rothenberg, I. and Heggie, I.G. (ed.), The Management of Water Quality and the Environment, New York, 1974.

Simmons, I.G., The Ecology of Natural Resources, London, 1977.

Singh, R.L. (ed.), India: A Regional Geography, Varanasi, 1971.

Singhal, R.P., Water Supply Engineering, Patiala, 1961.

Smith, K., Principles of Applied Climatology, London, 1975.

Steel, E.W. and Terence, J., Water Supply and Sewerage, London, 1979.

Strahler, A.N. and Strahler, A.H., Geography and Man's Environment, New York, 1977.

Sundar, A., Use of System Approach in Water Resource Planning, Indian Journal of Power and River Valley Development, Vol.XXIV, No.2, Calcutta, 1974.

Taylor, J.A. (ed.), Climatic Resources and Economic Activity, London, 1974.

Tiwari, A.R., Geography of Uttar Pradesh, New Delhi, 1971.

Todd, D.K., Groundwater Hydrology, New York, 1980.

Wadia, D.N., Geology of India, London, 1949.

Wadia, D.N. and Auden, J.B., Geology and Structure of Northern India, Memoirs of Geological Survey of India, Vol.73, Delhi, 1939.

Walton, W.C., Groundwater Resource Evaluation, New York, 1970.

Zimmerman, E.W., World Resources and Industries, London, 1951.

REPORT

Handbook of Districtwise Hydrogeological Information, Uttar Pradesh, Lucknow, 1984.

Hydrogeological and Hydrochemical Data of National Hydrograph Network Stations in Uttar Pradesh for the Year 1983, Lucknow, 1985.

Statistical Diary, Uttar Pradesh, 1985.

India, 1985.